The Effect of Physical Activity on Mental Fatigue Measured by EEG and Self-Reported Responses in Healthy, Active Individuals

A Dissertation

Submitted to the Department of Psychology

of the
Faculty of Humanities
at the
University of Johannesburg

by

Meghann Ashleigh Bruce
200908085

In Fulfilment of the Requirements
for the Degree of
MA Psychology (RD)

January 2019

Johannesburg, South Africa

Dr N. Joosub

ACKNOWLEDGEMENTS

I would like to acknowledge the following individuals for their support and assistance during the period of this study:

- Michael Ritchie: For your continuous support and care during many hours of writing and researching. Your patience and kindness have not gone unnoticed.
- My family: For their continuous support in allowing me to continue my love for learning.
- Ms Card: Thank you for allowing me the opportunity to continue my studies and for being a part of the positive experience.
- Dr Joosub: Thank you for your continuous feedback and support. Your mentorship has been appreciated.
- My colleagues: Thank you for your support and feedback, through some trying times of writing.
- The Participants: Thank you for your participation and endurance through the strenuous tasks.
- Andrew Ramsay: Your assistance with designing the tasks and allowing me access to your training facilities

ABSTRACT

Mental fatigue has been extensively researched after the occurrence of mental activities however, less research has been done on mental fatigue after the occurrence of physical tasks. Studies suggest that certain professional athletes are able to overcome the constraints of fatigue, suggesting that the fatigue experienced is a sensation rather than a physical occurrence. The purpose of this study was to investigate the effect of physical activity on mental fatigue, and to study whether the mental fatigue, if experienced, is subjective or objective in nature, after physical activity. The study measured biological markers, subjective mental fatigue, working memory and made use of electrocochleography (EEG). The EEG measured the neurological wave activity of 10 healthy and active participants, in a pre-intervention, intervention and post-intervention experimental setup. The intervention included physical activity, which was a 900-meter run followed by a 500-meter row and 15 calories on an air bike ride. The results indicated the participants were physically fatigued, due to the recorded biological markers in (See Table 4.2.1). Furthermore, there was an overall increase in the performance in the working memory task and reported feeling of mental fatigue among the participants. However, EEG recordings did not correlate with literature on objective mental fatigue, rather the results indicated an increase in alpha wave activity, which may be related to internal orientation of the brain and an increase in theta wave activity that correlates to internal attentional focus and decreased arousal. This suggests that the participants may have experienced a sensation of mental fatigue, due to physical fatigue initiated by physical activity, rather than objective mental fatigue. These findings may assist in further research on mental fatigue in professional athletes and overall performance

in physical tasks. Furthermore, this study could contribute to literature on the understandings of mental fatigue and how it is experienced by individuals.

Keywords: Mental fatigue, EEG, physical activity

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1: INTRODUCTION TO THE STUDY

1.1. Introduction

It is of importance to understand the effects of physical activity on various mental functions and physiological responses such as mental fatigue, in order to gain a deeper understanding of the connection between mental and physiological phenomena, which allows for advancement of knowledge within the context of sports. This may have an impact on the training of professional sportsmen and sportswomen, as well as an impact on the knowledge of sports psychology.

Fatigue is a multidimensional construct and is at times defined as a physical, and at other times, a mental phenomenon. Physical fatigue is often the result of depletion of the physiological resources caused by either illness or physical activity and manifests in clearly observable signs and symptoms (Tanaka & Watanabe, 2011). Mental fatigue is the result of extensive cognitive activity and primarily manifests in a subtler, often unobservable manner when compared to physical fatigue (Kato, Endo, & Kizuka, 2009).

Mental and physical fatigue may differ in cause and presentations, and the relationship between the two states has been researched. Mental fatigue has been found to have a negative impact on physical performance in soccer players (Smith, Coutts, Merlini, Deprez, Lenoir, and Marcora, 2016), where it was found that mentally fatigued players produced more ball control and passing errors. MacMahon and Schücker's (2014) research on the impact of mental fatigue on physical performance has found that mental fatigue has an adverse effect on physical performance, however, no physiological changes occurred or were recorded.

Marcora, Staiano, and Manning (2009) studies showed similar results on the impact of mental fatigue on physical performance and was able to show that perceived effort impacted the participants, physical performance, showing an overall decrease. These findings suggest that mental fatigue is at times experienced as a psychological state rather than a physiological state (Connon, 2016). The above research shows a connection between mental functions, such as mental fatigue and physical activity, although it is not in the direction on which this study is focussed on, furthermore providing a different view of the relationship between physical activity and mental fatigue.

Further studies by Eston, Faulkner, Gibson, Noakes, and Parfitt (2007) and MacMahon and Schücker, (2014), have found associations between mental fatigue, the performance of the physical activity and the appearance of physical fatigue. These studies suggest that mental fatigue is experienced as a sensation, rather than a physiological occurrence, during physical activity, suggesting that mental fatigue can be experienced subjectively and still impact physical performance. Noakes (2011) developed the central governor model (CGM) on fatigue. The CGM suggests that in fatigue is controlled solely by the brain (Noakes, 2011) During the CGM, the sensation of fatigue is believed to serve as a protective measure during physical activity, which makes use of sensory input in order to ensure that the body remains in homeostasis. Furthermore, Noakes suggested that the sensory input is received from physiological and psychological feedback mechanisms (Connon, 2016). The above may indicate that during physical activity, mental fatigue is experienced as a biological alarm, that reacts to feedback from the body (Eston, et al., 2007). These studies make suggestions that a mental function, such as mental fatigue may be subjective in nature and therefore, experienced as a sensation. This adds to the unique relationship between physical activity and mental fatigue.

From previously mentioned literature, it becomes clear that mental fatigue has a direct impact on physical responses and overall physical performance. (Marcora, et al., 2009). Therefore, investigating the impact physical activity has on mental functions, such as fatigue may provide a further understanding of the relationship between physical activity and mental fatigue. This may provide theoretical contributions to the literature on mental fatigue and the role it plays in the field of sports psychology (Schiphof-Godart, Roelands, & Hettinga, 2018). Furthermore, the symptoms of mental fatigue such as increased distractibility and decreased flexibility (Boksem, Meijman, & Lorist, 2005) and aversion to continuing tasks (Desmond & Hancock, 2001) make it an important state to study, in order to provide insight into individuals or patients that may be experiencing similar symptoms. From a clinical setting, a greater understanding of mental fatigue may impact the training and conditioning of professional athletes, military service personal (Marcora, et al., 2009) and treatment of individuals that are experiencing mental fatigue due to illness or injury (Johansson, Bjuhr, & Ronnback, 2012).

1.2. Aim of the Study

The purpose of this study was to investigate the relationship between physical activity and mental functions, further and to provide an understanding of the impact of physical activity on mental fatigue. The following three specific objectives were set to achieve the broad aim of the study:

1) To understand whether mental or cognitive functions, experienced due to physical activity, contribute to mental fatigue,

2) To compare the impact that physical activity has on mental fatigue.
3) To determine, if experienced, whether the mental fatigue from physical activity is an objective experience and measurable or whether the mental fatigue experienced is a sensation and only subjectively reported.

These three objectives will contribute to the specific flow of the study to achieve the aim.

1.2.1. Investigative Question and Hypothesis.

Can one find objective evidence of mental fatigue, after physical activity by using an Electroencephalograms (EEG's) as a measure? It is hypothesized that if mental fatigue is experienced by individuals, from physical activity, is may be subjective in nature and not measurable by an EEG. It is further hypothesized that the mental fatigue experienced will be subjective in nature and only recorded by self-report. Therefore, the null hypothesis (H_0) is that physical activity causes objective and measurable mental functions that induce mental fatigue that is visible on an EEG. The alternative hypothesis (H_1) is that physical activity causes a sensation of mental functions that induce mental fatigue that is not visible on an EEG and is rather self-reported.

1.3. Overview and Structure of Study

The aim of this study was to determine if the mental fatigue experienced after physical activity is objective or subjective in nature. Chapter 2 will discuss the concepts of fatigue as a physical and a mental occurrence, the relationship, and measurements of mental and physical fatigue. Furthermore, in Chapter 2 the neural mechanisms involved in both physical and mental fatigue will be discussed further, followed by the topic of mental fatigue as a sensation. Chapter 3 will outline the research methodology, discussing the research design, participants, procedures, statistical analysis, and ethics. Chapter 4 will display the results of the study, followed by chapter 5, where the findings, limitations, and recommendations for further research will be discussed in detail.

1.4. Conclusion

The aim of this study is to further investigate the impact of physical activity on mental functions that may cause mental fatigue and whether it will be objective or subjective in nature. The findings of this study may have theoretical and clinical implications, as discussed above. The next chapter will examine former and current research pertaining to the investigative question.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

The purpose of this chapter is to discuss past and current studies on the relationship between physical activity and mental functions, that may lead to mental fatigue. Furthermore, the chapter will discuss subjective and objective mental fatigue. The studies discussed will examine the instruments of measurement and the relationship between physical activity and mental fatigue. The literature available on the topic of the impact of physical activity on mental fatigue is limited and therefore, older studies are included in this literature review to ensure a thorough discussion of the topic of mental fatigue.

2.2. Fatigue

Fatigue is a multifaceted phenomenon that is experienced across ages, cultures, and genders at different variations. The universal definition of fatigue is that it is an internal state or condition, in which an individual experiences a reduced capacity to perform mental and physical activities, which have been associated with depleted energy caused by excessive mental and/or physical activity (Allen, Reber & Reber, 2009; Ishii, Tanaka, Watanabe & Yamano, 2014). Furthermore, fatigue can be defined as a reduction in the function of the allocation of resources caused by an immune or emotional state (Desmond & Matthews, 1997). The above-mentioned definitions illuminate that fatigue can occur both physically and mentally. Mental fatigue differs from physical fatigue and will be discussed further in the section below.

2.2.1. Physical Fatigue

Physical fatigue is often the result of depletion of the physiological resources caused by either illness or physical activity and manifests in clearly observable signs and symptoms (Shigihara, et al., 2013). For the purpose of this study, the causes of physical fatigue from physical activity, along with the symptoms and recovery, will be discussed.

2.2.1.1. Causes, symptoms, and recovery from physical fatigue

In order to comprehend the symptoms of physical fatigue from physical activity, the cause of physical fatigue during and after physical activity needs to be understood. During physical activity, the body endures a variety of physiological adaptations that depend on the intensity and type of activity involved. These adaptions include increased cardiac output and increased blood pressure due to an increase in overall blood flow (Rivera-Brown & Frontera, 2012). These physiological adaptations lead to the depletion of resources within the different systems of the body and the production of by-products due to biological processes. The following, although not inclusive, is a list of common causes of physical fatigue during physical activity: lactic acid accumulation, a decreased rate of energy delivery, failure of the muscle fibres' contractile mechanisms and alternations to neurological control of muscles (Kenney, Wilmore, & Costill, 2015).

Common observable and measurable symptoms of the depletion of resources and the production of by-products immediately after physical activity include shortness of breath, increased body temperature, increased heart rate and blood pressure (Rivera-Brown & Frontera, 2012). Individuals that experience such symptoms often report the abovementioned symptoms in a subjective manner and tend to leave the physical activity prematurely (Kenney et al., 2015).

An important characteristic of physical fatigue is that it is reversible by efficient rest and recovery (Kenney et al., 2015). Research conducted on the effects of sleep on athletes' performance showed that extended sleep and rest, contribute to an overall improvement in athletes physical performance, showing that peak performance can be reached after substantial rest (Mah, Mah, Kezirian, & Dement, 2011).

The above literature shows that physical activity can be a cause of physical fatigue, which can be measured objectively. The measurable constructs are biological and physiological responses, that contribute to physical fatigue. The above refers to the physiological functions of the body during physical activity, below, further literature will be discussed about physical activity and its relationship to mental functions, such as mental fatigue.

2.2.2. Mental Fatigue

Mental fatigue is often the result of extensive mental activity and primarily manifests in a subtler, often unobservable way when compared to physical fatigue (Kato et al., 2009). One of the definitions of mental fatigue is the experience of cognitive impairment due to extensive mental concentration (Reber, Allen, & Reber, 2009). Many studies have been conducted on the numerous facets that mental fatigue consists of, on which different theories of mental fatigue have been constructed. The impairment in mental functioning is an aspect that makes any study on mental fatigue an important one, as these impairments may affect daily living of individuals who experience mental fatigue, which will be discussed in more detail below.

2.2.2.1 Causes, symptoms, and recovery from mental fatigue

Symptoms of mental fatigue are often unobservable and subjective in nature, a vast difference when compared to physical fatigue. The symptoms are usually characterised by impairment of cognitive functioning. The impaired cognitive functioning induced by mental fatigue results in deficits in information processing and manifests in changes in behaviour, attention, and memory (Desmond & Hancock, 2001). The changes in behaviour and mood include an aversion to continuing with tasks which have little to no reward value, changes in mood and negative affect (Desmond & Hancock, 2001). The changes in attention include decreased arousal levels as well as impaired concentration or inadequate selective and sustained attention (Van der Linden & Eling, 2006) and a change in attentional focus (MacMahon & Schücker, 2014). It is also argued that mental fatigue results in impaired short-term memory and recall (Johnson, DeLuca, & Diamond, 1998). These deficits can have significant effects on daily living and society as a whole. These impairments contribute to an increase in human error which may result in accidents (Boksem et al., 2005), impaired decision making (Punja, Shamseer, Olson, & Vohra, 2014) and loss of productivity in the workplace. The symptoms of mental fatigue are often not reversible by rest and recovery alone.

The difference between the symptoms, causes, and recovery from mental and physical fatigue are important to note. There are clear physiological responses that differ between the two, that may make them appear unrelated. However, both share the definition of an internal state and depletion of resources, that appears to lead to the reduced capacity to complete tasks, whether physical or mental (Allen et al., 2009; Ishii, et al, 2014). Further clarification on the measurement of mental fatigue will be discussed, in order to evaluate the relationship further.

2.2.2.2. Measurement of Mental Fatigue

The measurement of mental fatigue is unique in the fact that it can be measured subjectively and objectively. Offner (1911), a pioneer in the study of mental fatigue, distinctly divided the objective measure of mental fatigue into two groups of measurement – physiological and psychological. The research explains the differences between the measurement of subjective mental fatigue that was experienced by psychological reporting and evaluation, and objective mental fatigue, which was evaluated by physiological measurements.

The subjective measure of mental fatigue determines a standard of measurement in the subjective symptoms or conscious awareness of the individuals experiencing mental fatigue (Offner, 1911). Subjective measures have proven to be less reliable due to the many factors that can affect an individual's subjective experiences, such as psychological factors. The objective measure of mental fatigue assesses the measurable biological symptoms of mental fatigue (Offner, 1911).

To elaborate on Offner's (1911) study on mental fatigue in the schooling environment, his study consisted of objective measures; to measure the physiological measurement of mental fatigue. These measurements included the dynamometer, the ergograph, measurement of respiration, pulse, and a range of accommodation of the students' eyes – many of which are still used today to measure mental fatigue. To measure the psychological factors, Offner used measures such as esthesiometry, kinematometer, measurement of fatigue by liminal values, methods of time estimates, methods of continuous work and duration of mental processes, some of which were self-reports and subjective in nature.

Modern technology and extensive research have allowed for the development of measures for both subjective and objective measures for psychological and physiological occurrences, even mental fatigue, many of which will be discussed below.

Researcher Hans Berger was the first to suggest in his research that mental fatigue may be recorded by electroencephalography (EEG) in 1929. Since then, much research has been done on the EEG as a reliable and valid measure of mental fatigue. Furthermore, newly developed, reliable, and valid subjective tests have been developed to measure mental fatigue, such as self-reports and psychometric assessments.

The relationship between objective and subjective mental fatigue, make mental fatigue an interesting and dynamic research topic. As previously mentioned, the nature of mental fatigue alone, such as not having observable symptoms makes the use of an EEG imperative, in obtaining a further understanding of it. In the section below, the physiology of brain wave frequencies, that are recorded on EEGs will be discussed further in order to provide further insight into the mental functions behind mental fatigue.

2.3. The physiology of brain wave frequencies

Fluctuations in brain wave frequencies are generated by electrical current alternations within numerous sites of the brain (Teplan, 2002). These electrical current alternations are caused by activation of neurons during an excitable period in the brain, also known as a synapse, due to the release of ions such as sodium, potassium, calcium, and chlorine. There are numerous types of synapse that release neurotransmitters that contribute to the electrical current alternations. In order for an

EEG to record alternations in electrical current, a great number of active neurons is required (Teplan, 2002). Activation of neurons can be enticed by performing different task and activities, which cause electrical current alternations in various anatomical structures in the brain that are related to performing said tasks and activities. This may then be recordable on an EEG, which gives further insight and understanding of the meaning and functions of brain wave frequencies.

2.3.1. Frequencies of brain wavelengths and function

Electrical current or neural-electrical alternations are recorded by an EEG that measures the brain wave frequencies of the brain by electrodes connected to a specialised cap (Cheng & Hsu, 2011). It is commonly used in studies due to the non-invasive nature of measurement.

Generally, four brainwave frequencies are observed and the implications of the alternations of these frequencies are of utmost importance to this study. These frequencies consist of fast wavelengths; alpha wavelengths and beta wavelengths and slow wavelengths; theta and delta wavelengths (Millett, 2001).

Alpha wavelengths are between eight and 12 Hertz (Hz) and are associated with an awake and relaxed state in individuals, this wave is also prominent in stage one of sleep (Stern, Ray, & Quigley, 2001). A reduction of a variation of the alpha wavelengths band, known as the mu wavelength, may occur when an individual is asked to perform a cognitive activity (Stern, Ray, & Quigley, 2001). Research has shown that increased alpha frequencies play an important role in the suppression and selection of attention (Klimesch, 2012).

Beta wavelengths are between 12 and 20 Hz and are associated with an alert individual; these wavelengths are associated with the performance of cognitive activity (Stern, et al., 2001). Beta wavelengths can be associated with logical thoughts and an awakened state, however, an increase in the wavelength tends to have a stimulating effect and this manifests in stress, high arousal, and an inability to remain in a relaxed state. The suppression of these wavelengths manifests in poor cognitive processing and a deflated state of being (Priyanka, Abhang Bharti, & Gawali Suresh, 2016).

Theta wavelengths are between four and eight Hz and are associated with low levels of alertness. Theta wave activity is found in stage two and three of the sleep-cycle. Additional research has shown theta wave activity to be associated with cognitive processing and attention (Stern, et al., 2001). This research has shown that increased theta wave activity has been found as a response during actions that require internal exploration, internal searching, and motor behaviour. In addition, the increase in the theta wavelength is known to be associated with cortico-hippocampal interaction (Basar et al., 1999). A study by Klimeschen, Schack, Bärbel & Sauseng, (2005) suggests that an increase in theta wave activity is associated during retention and retrieval of memories. This change in activity oscillates in a wave-like formation across the brain from anterior to posterior regions (Klimesch, Schack, & Sauseng, 2005). Furthermore, increased theta wave activity has been found to be associated with the objective recording of fatigue (Craig, Tran, Wijesuriya, & Nguyen, 2012).

Delta wavelengths are between one and four Hz and are associated with sleep in healthy individuals (Stern, et al., 2001). Delta wave activity has been associated with internal concentration and cognitive processing. Research suggests that an increase in delta wave activity inhibits the prefrontal cortex, which then reduces cognitive and emotional engagement (Thalía, 2013).

The activities or tasks that cause alternations in these brain wave frequencies vary. However, knowledge of the functions of the lobes of the brain ensures a better understanding of the reasons why certain brain wave frequencies appear in a particular lobe, at a particular time.

2.4. Fatigue compared to Somnolence

Fatigue is and can be commonly misunderstood as somnolence due to similar symptoms, however, there are multiple physiological differences between fatigue and somnolence. Therefore, for the purpose of this research, it is essential to understand the physiology of sleep and how it is either relates to, or differs from, fatigue (Mullins, Cortina, & Drake, 2014).

Desmond and Matthews (1997), differentiated fatigue and somnolence by explaining somnolence as a reduction in resources caused by multiple physiological factors and interruptions in the ultradian rhythm (a recurrent period or cycle repeated throughout a 24-hour circadian day), which differs from fatigue, where resources are said to be present but are unable to be allocated appropriately. The ultradian rhythm is modulated by an individual's circadian cycle and specifically the sleep and wakefulness cycle. This is a defining difference between fatigue and somnolence. Reduced resources result in a state of somnolence, whereas in a fatigued state the resources do not have to be reduced and are present. It can, therefore, be stated that when one is experiencing fatigue, the resources are present to perform voluntary mental and/or physical activities, however, there is an impairment in the allocation of resources and there is no involvement of the ultradian rhythm.

2.5. Studies on Mental Fatigue and Physical Fatigue

It is apparent, from previous literature (Ishii, Tanaka, Yamano, & Watanabe, 2014) and (Reber, Allen, & Reber, 2009) that both physical and mental fatigue are associated by a mutual phenomenon but vary in several ways. Studies such as those completed by Smith, et al., (2016) and Marcora, et al., (2009) on the correlation between mental fatigue and physical fatigue has been focused on exploring the effects of mental fatigue on physical performance. Such studies, like the ones mentioned above, have found that overall, mental fatigue reduces an individual's physical performance (MacMahon & Schücker, 2014). Results of such studies suggest that, although there was a decrease in physical performance of the mentally fatigued participants, there was no difference in the physiological symptoms of mentally fatigued participants and non-fatigued participants. These findings suggest that there were no signs of physical fatigue. Such studies will be discussed in detail below.

Marcora, et al., (2009) conducted a study where participants attended three experimental sessions. The first session was an exercise test in which the participant's oxygen uptake, peak power output and rating of perceived exertion were measured whilst partaking in physical activity (cycling). The second session involved the participants answering a mood questionnaire and blood tests were taken for glucose measurement. Afterward, participants were divided into a fatigue and non-fatigued group after going through different treatments. Mental fatigue was induced by a 90-minute cognitive task, whilst the control group watched documentaries for 90-minutes. All the participants' heart rates were measured. The participants were then asked to fill in the mood questionnaire and a motivational questionnaire to measure motivation for the upcoming physical task. The physical activity (cycling) occurred. Further blood tests were taken to measure the glucose levels. The study found that mental fatigue reduces physical performance overall, however, there were no physiological differences between the fatigued participants and the non-fatigued participants. The perception of effort was found to be the cause of the impaired physical performance, rather than impairment in the cardiorespiratory or muscular mechanisms. This study suggests that mental fatigue has no physiological impact on individuals during physical tasks however, it appears to have a psychological impact that affects performance, which was reported subjectively. Therefore, suggesting that mental fatigue could be caused by a mental function, rather than a physiological occurrence, and therefore subjective in nature.

MacMohan and Schücker (2014) investigated the effect of mental fatigue on physical performance, specifically in a paced running task. The results yielded by the study were similar to that of Marcora, et al., (2009). The participants were instructed to performed two 300-metre runs, one under non-fatigued conditions and one after being mentally fatigued. Mental fatigue was induced by a cognitive task being performed for 90-minutes and the control group watched documentaries for 90-minutes. To measure physical performance, blood samples were taken, and heart rates were measured before and after each trial. To measure subjective psychological constructs, a mood scale, attentional scale, and rate of perceived exertion were completed. The study found that there were no differences in physiological measures such as heart rate and neuromuscular activity in the mentally fatigued participants. However, mental fatigue caused a reduction in the physical performance of these athletes. A notable finding of this study, which differs from the previous study, was that the mentally fatigued participants showed no difference in perceived exertion and attentional focus compared to the non-mentally fatigued participants. This suggests that the mentally fatigued participants reported no difference in their psychological state of being, even though their performance was impacted. This result of this study differs, due to the fact that the participants were able to self-report no difference in their psychological state of being, even though the overall physical performance had decreased due to mental fatigue. This suggests that a mental function that may cause mental fatigue could possibly be dynamic in nature and could depend on the physical activity involved.

The results of the studies pertain to questions about subjective feelings of mental fatigue and an individual's perception of mental fatigue during physical activity. Mental fatigue appears to have an influence on physical performance without affecting peripheral physiological mechanisms. This is an important differentiating factor between physical fatigue and mental fatigue. Therefore, it is of importance to understand the underpinnings of the neurological mechanisms involved in physical and mental fatigue.

2.5.1. Neural Mechanisms involved in Physical Fatigue

It is important to mention that there is a marked neurological electrical current alternation during physical fatigue. As mentioned, physical fatigue is induced by depletion of the physiological resources caused by either illness or physical activity (Tanaka, Ishii, & Wantabe, 2013). During physical activity, physiological resources are being depleted as the activity continues, the same would occur when an illness demands an immunological response from the body. The result of the neuro-electrical activity of the brain will be discussed below.

Raveendran (2007) investigated the relationship between alpha brain wave frequencies and physical fatigue. The participants were instructed to perform a handgrip task, by contracting the muscles of the hand with maximum force with both hands until not being able to continue. An EEG was used to record the neuro-electrical current alternations in the brain. The results indicated that there was a reduction in the alpha frequency in the motor cortex region of the brain. This reduction in alpha brain wave frequencies may suggest that the participants were experiencing a change in their state, from alertness to a more relaxed state, especially in relation to motor functioning. Therefore, it may be stated that a reduction in alpha wavelengths is associated with motor functioning.

Moraes*,* Ferreira, Deslandes, et al. (2007) investigated the alternations in alpha and beta brain wave frequencies after physical exercise that required maximum effort. An EEG was used to record the alternations. Participants were required to part-take in an eight-minute resting EEG (eyes closed) recording session followed by a physical exercise test, using a stationary cycle ergometer. After the physical exercise test, participants partook in another identical eight-minute EEG recording. The results indicated that there was an increase in beta frequencies in the frontal and central areas of the brain. This increase in the beta wave activity suggests a change in the state towards cognitive activity. Therefore, suggesting that after physical activity, there may be increased cognitive activity. This is important to note, as it is often not a symptom of mental fatigue.

Schneider, Brummer, Abel, Askew, and Struder (2009) investigated the region of neuro-electrical alterations in the brain to show the effects of exercise on participants and the link to the participant’s physical exercise performance. EEG recordings were recorded for five minutes, followed by biological measures such as heart rate, lactic build up and oxygen uptake, before and after physical fatigue was induced. The physical fatigue was induced by treadmill running, arm crank and bicycle movements. The results showed that there was an increase in frontal and parietal alpha frequencies post-exercise and an overall increase in beta frequencies in the Brodmann area 7, in the temporal lobe. This study contradicts the previous study by Raveendran (2007), where a reduction in alpha wave frequencies was found and this may be due to the physical task differences in the studies. This study made use of a variety of physical tasks that engaged the body, rather than handgrip alone. The increase in alpha wave frequencies suggests a state of alertness in the participants, post-physical activity and during a physiological state of fatigue. This study correlates with Raveendran (2007), as there is an increase in beta wavelengths and an increase in alertness post-physical activity, where Raceendran mentioned increased cognitive activity.

Tanaka and Watanabe (2011) investigated the neuro-electrical alternations in the brain when central fatigue was induced. Central fatigue is known as a decline in the ability to voluntarily activate muscles during physical fatigue (Tanaka & Watanabe, 2011). The study made use of a magnetoencephalographic (MEG) system. The participants were instructed to perform a repetitive right-hand grip but contracting the muscles of the hand with maximum force, in order to produce a physical task that would induce fatigue. MEG recordings were done before and after the task. The results indicated that there were differences in the beta brain wave frequencies. Beta frequencies were found to be decreasing in the left sensorimotor area and increasing in the right sensorimotor area of the brain, after the fatigue-inducing task. The variations in these results may be due to the use of one hand. Beta frequencies tended to increase in the prefrontal area during the fatigue-inducing task. This increase in beta wave frequencies correlates with the above study, where there was an increase in the temporal lobe region of the brain during a state of physical fatigue.

Kubitz and Mott (1996) examined the effects of aerobic exercise on neuro-electrical current alterations recorded by an EEG. The participants were instructed to partake in a 10-minute adaptation period. Physical fatigue was induced by a 15-minute stationary cycle and the control group was instructed to watch a videotape for 15 minutes. Another 10-minute adjustment period was induced after the experimental and control tasks. EEG data was collected from the last two minutes of each adaption period and the last two minutes of every five minutes during the experimental and control tasks. The results from the EEG recordings indicated that there was a reduction in alpha frequencies and an increase in beta frequencies during the exercise condition. Alpha and beta frequencies did return to baseline after the physical activity. The same results were not produced by the control group. The decline in alpha wave frequencies are similar to that of the study by Raveendran (2007), but contradict the results of the study by Schneider, et al., (2009). This could be due to the variation of the physical task in the study. The increase in beta wave frequencies correlates with the previous studies of alternations in the neuro-electrical alternation of the brain during physical activity and a state of physical fatigue.

To summarize the above, it appears that physical fatigue induced by physical activity influences the alternations of alpha and beta frequencies in the brain. Most studies found that alpha frequencies tend to decrease with physical fatigue and beta frequencies tend to increase. The main anatomical regions in the brain where these alternations were found were the frontal, parietal and temporal lobes. Furthermore, the results from the study tend to show that individuals experience increased alertness and cognitive activity post-physical activity.

2.5.2. Neurological measurements of Mental Fatigue

For the purposes of this research, it is important to understand the underpinnings of mental fatigue from a neurological foundation, in particular, a neural-electrical and anatomy basis. This is essential to understanding the differences and similarities to physical fatigue.

Numerous methods are used to measure mental fatigue as will be seen below. The measures used often differ by measuring objective mental fatigue and subjective mental fatigue. The next set of studies look at the physiology and psychology that are the basis of mental fatigue and symptoms that arise from mental fatigue.

It is significant to look at the anatomical structures involved in mental fatigue and their functioning to help have a better understanding of what neurological factors are activated with mental fatigue. The following is a collection of studies on mental fatigue that made use of objective and subjective measurements. These studies will provide further insight into the mental functions involved in mental fatigue. Furthermore, the studies will provide information on the brain wavelength frequencies and neurological sites associated with the mental functions related to mental fatigue.

An early study conducted by Cheng and Hsu (2011) investigated the neural electrical response of mental fatigue that was induced by response tests in visual display terminal (VDT) tasks in order to compare behaviours and physiological responses to mental fatigue. The study consisted of a pre-intervention and post-intervention phase. During the pre-intervention phase, an EEG recording was made for 5 minutes, followed by a modified 15-minute Eriksen flanker task with word stimuli and then a NASA-Task Load Index (NASA-TLX) scale, which consists of six component scales to measure overall perceived workload. The intervention consisted of 30 minutes of mental arithmetic, 60 minutes of data entry and another 30 minutes of arithmetic. The post-intervention phase included an EEG recording, that was 5 minutes in length, followed by a modified 15-minute Eriksen flanker task with word stimuli and then a NASA-Task Load Index (NASA-TLX). The results of the objective measure, the EEG, showed that there were alternations in the neuro-electrical activity. Overall, there was an increase in alpha and theta frequencies in the occipital lobes. The subjective measures of mental fatigue, the NASA-TLX showed that there was a tendency for the participants to subjectively feel mental fatigue however, there was no significant correlation between the subjective measures and objective measures. The increase in the alpha wave frequencies differs from the reduction alpha wave frequencies that occur during physical fatigue. Furthermore, the increase in theta wave frequencies differentiated mental fatigue from physical fatigue. The increase in theta wave frequencies suggests an alternation in attentional focus, motor behaviour and low levels of alertness (Basar, et al., 1999). The results of the study suggest that when an individual is mentally fatigued by a cognitive task, they may experience a decrease mental functions, such as attention and alertness, which differ from physical activity.

To determine the role of attention in mental fatigue, the study by Boskem, et al., (2005) investigated the effect of mental fatigue on behaviour and whether it was associated with a reduction in action monitoring, as well as the relation between mental fatigue, attention, and motivation. This study observed symptoms of mental fatigue reported by mentally fatigued individuals. Individuals reported difficulties in concentration and focus of their attention. Attention and attentional focus were the main focus of their study. Attentional focus allows individuals to actively ignore irrelevant information that may interfere with the current goal – so that they do not become distracted (Boksem, et al., 2005). Participants performed a visual attention task for a period of three hours with no rest. The participants had to focus their attention on relevant cues and report the positioning of one out four letters according to the cues given. This allowed the researcher to detect change in performance while the participants became increasingly mentally fatigued. An EEG and event-related potentials (ERPs) were used to measure any neurophysiological changes that were related to mental fatigue and attention. The results of the objective measures, EEG recordings, showed that delta waves were prominent but did not change as time on task continued however theta waves increased with time on task. Lower-power alpha waves increased with time on task, upper-alpha power waves were largest over occipital region, and power also seemed to increase with time but did not prove to be significant. Beta power waves were the largest in frontal sites and also increased with time, although it was a small difference. Therefore, mentally fatigued participants showed decreased arousal, which resulted in an increase in alpha and theta waves. The anatomical structures that were the sites for the frequencies are as follows; alpha frequencies in the parietal and occipital regions, beta frequencies in the frontal lateral sites, theta frequencies in frontal sites and delta frequencies consistent throughout all sites mentioned above. To measure the subjective fatigue that the participants were experiencing, participants were presented with a visual analogy scale so that they could rate/indicate their levels of aversion to the tasks at hand. This was given to the participants at multiple times throughout the experiment. The results from the subjective measure of fatigue showed that the participants' aversion to continuing tasks increased from a score of one at the beginning to 8.6 at the end and that performance of tasks declined with time. An interesting result of this study is that they found that if the participants were motivated, their action monitoring seemed to return to normal, showing that there is a strong motivational component to mental fatigue. This study concluded that one of the effects of mental fatigue appears to be the inability for participants to allocate their attention efficiently. These results account for the increased distractibility and decreased flexibility in characteristics of fatigued people. There was a correlation between aversion scale and the lower-alpha frequencies that increased, suggesting that the mental function of aversion could be related to mental fatigue. This study shows that mental fatigue is associated with reduced action monitoring and therefore, attention. The consistent delta wave activity could correlate with previously mentioned research, where delta waves frequencies were found to be associated with decision making. The increase in theta wave frequencies could be associated with decreased arousal, similar to the function of theta waves in sleep, however, increased theta wave frequencies have been found to be associated with cognitive processing and attention. The subjective measure showed a correlation between subjective feelings of mental fatigue and decreased task performance. This study has results that correlate with the previous study, Cheng & Hsu, (1999), revealing a pattern in alternation in neuro-electrical activity in the brain during a state of mental fatigue, that may allow mental fatigue to be observed on an objective measure such as an EEG.

Scheeringa, Bastiaansen, Peterson et al., (2008) investigated how frontal lobe, theta frequencies correlated with the default mode network (DMN) in resting state. The DMN consists of the frontal regions of the brain, the posterior cingulate cortex, the inferior parietal and frontal cortices, the middle temporal lobe, and the cerebellum. These regions in the brain make up a network that is regularly observed to disengage during attention-demanding cognitive tasks. This study only made use of objective measures. Participants were selected and instructed to complete a working memory task for one hour that was divided into three sessions. The EEG cap was applied and used during the task. After completion of the experiment, a resting state measurement was completed. The participants were asked to observe an image for a total of 10 minutes. Participants were then scanned by MRI. Data from the resting states were used and the results found that frontal theta wave frequencies do not correlate with rested individuals. This study suggests that individuals that are rested, show no alterations in theta wave activity, therefore suggesting that alternations are observed during un-rested individuals, supporting studies on the association of mental fatigue and theta wave frequencies alternations.

A study conducted by Zhao, Zhao, Liu, and Zheng (2012) investigated the EEG measures and ECG measures of mental fatigue on driving simulated tasks. In the pre-experiment phase of the study participants took place in an oddball task in which the participants had to respond to target stimuli that occur infrequently and irregularly. The oddball task consisted of a red and a green circular image randomly displayed on the screen. Mental fatigue was then induced by a 90-minute driving simulation task. The participant's self-report of mental fatigue was recorded. Once mentally fatigued, the participant took place in the oddball task again. They made use of self-report as a subjective measure of fatigue and EEGs as an objective measure of fatigue. The objective measures of the EEG showed that there was an increase in theta wave activity in the central region of the brain, an increase in alpha wave activity in the central and occipital regions with a shift towards the anterior regions. A slight decrease in beta wave activity was found that could correlate with previous knowledge about a decrease in beta wave frequencies being associated with a decreased arousal and alertness. The subjective measures showed that the self-report of fatigue increased with time and that participants reported feeling tired from the task. This study further supports the role of alpha and theta wave frequencies in mental fatigue and the correlation between subjective feelings of mental fatigue and objective recording.

A study conducted by Craig, et al., (2012) investigated the relationship between brain wave activity associated with fatigue in 48 nonprofessional healthy drivers, as they participated in a simulated driving task. The study consisted of a pre-intervention phase, invention, and post-intervention phase. During the pre-intervention phase of the study, participants' brain wave frequencies were recorded using an EEG. The intervention included the use of a driving simulator that the participants partook in until there were observable signs of fatigue. These observable signs included assessing the number of times that a participant closed their eyes, yawned, and nodded. Once fatigued, the participants entered the post-intervention phase of the study, where further EEG recordings were done. All participants were asked to complete the Chalder Fatigue Scale (CFS). The objective measure of the EEG found that there were no significant changes in delta wave activity in the frontal, posterior and central sites within the brain. However, there were significant changes in the theta wave activity in the frontal, central and posterior sites within the brain; there was a significant increase in theta waves in all regions. The study further found that there were significant changes in alpha wave activity in the frontal, posterior and central areas within the brain; there was an overall increase in alpha wave activity. The study found that there were significant changes in beta wave activity in the frontal and central sites; there was an increase in beta wave activity in the frontal and central sites. This study further supports the association of mental fatigue with theta and alpha wave frequencies. However, the increase in the beta wave frequencies differs from previous studies. This could be due the nature of the experiment and the simulated driving task, which may produce beta wave frequency cognitive functioning and physical fatigue.

A study conducted by Barwick, Arnett, and Slobounv (2013) investigated how an EEG recording would correlate with fatigue during neuropsychological assessments. Participants were instructed to complete a variety of ability neuropsychological assessments. The study involved the objective and subjective measures of fatigue. The objective measures were measured by the EEG while the participants underwent the neuropsychological testing. The results showed an increase in theta wave frequency in the frontal central area and the parietal area. The results also showed a change in alpha wave frequencies that moved from occipital regions to anterior regions on the brain. The subjective measure was the use of a self-report on fatigue, results showed an increase in self-reported fatigue. This correlation between reported mental fatigue and alpha and theta wave frequencies supports previous studies and continues to show a repetitive pattern associated with mental fatigue.

Ishii, et al., (2014) conducted a study to investigate the neural substrates of the self-evaluation of mental fatigue. The rationale behind the study was that the sensation of mental fatigue is of utmost importance in the physiology of the human body but sometimes the sensation of fatigue is overestimated and causes severe fatigue that will decrease mental and physical performance. The objective measure used to measure the mental fatigue in this study was a MEG. The results showed that there was no significant difference between alpha, beta, and theta waves but there was a decrease in delta waves in the dorsolateral prefrontal cortex and the posterior cingulate cortex. The subjective measure of mental fatigue that was used was the

Checklist Individual Strength (CIS) questionnaire, which consists of 20 questions and is designed to assess the daily level of fatigue sensation. There was a correlation between the subjective feeling of fatigue and the delta wave frequency reduction in the dorsolateral prefrontal cortex and the posterior cingulate cortex. The results from this study contradict previous studies that found an association between subjective mental fatigue and alpha and theta wave frequencies. However, previous studies induced mental fatigue, where-as this study studied the self-evaluation of mental fatigue, suggesting that the sensation of mental fatigue differs neurologically from mental fatigue induced by cognitive tasks.

A study conducted by Wacher, Rasch, Sanger, et al., (2014) investigated the theories of EEG studies on mental fatigue and how the anatomical area relates to such frequencies. Participants were made to perform a four-hour-long spatial correspondence task. The task led to a slight decrease in accuracy and the reaction time remained stable throughout the task. The results from the EEG showed a marked increase in theta wave activity in the frontal region compared to the beginning of the task and the ending of the task. There was also a slight increase in alpha wave activity in the occipital region of the participants, however this only increased slowly and then stayed stable for a period of two and half hours. No subjective measures were used in the study. The researchers state that the increase in theta wave activity in the frontal region may be showing the exhaustion of resources that accompanies mental fatigue, or it could be showing mental effort, which correlates with previous studies.

2.5.2.1. Summary of signs of Mental Fatigue on EEG

The research on the EEG and brain wave frequencies in mental fatigue is vast and sometimes contrasting. To summarise the above information, each frequency will be discussed independently and commented on below.

The alpha brain wave frequency's role in mental fatigue varies from increasing and decreasing across studies. Studies have mentioned that alpha frequencies increase with increasing fatigue. Hanslmayr, Gross, Klimeschen, and Shapiro (2011) proposed that increases in alpha power are related to changes toward internally oriented brain states that might hamper the detection and identification of stimuli. The main anatomical structures in the brain that correlate with an increase in alpha frequencies during studies is the parietal and occipital sites (Boksem, et al., 2005). The anteriorization of alpha activity is important to note.

The beta brain wave frequency's role in mental fatigue also varies from increasing and decreasing across studies. Studies such as Zhoa et al., (2012) have shown that higher frequencies such as the beta frequency usually decrease in amplitude (decreased frequency) when related to mental fatigue, which indicates a decrease in arousal, similar to the results from physical fatigue. Studies such as those by Priyanka et al., (2016) that involve cognitive activity usually show an increase in beta wave activity in the lateral frontal sites or sites associated with the task at hand. These contradictions can be explained by the nature of the activities in the studies, where some are either physical tasks or cognitive tasks.

The theta brain wave frequency also varies among different studies. Generally, EEG studies on mental fatigue report an increase in theta wave activity. Increased theta wave activity may suggest sleep and a decreased state of arousal, such as that in stage 2 of the sleep cycle. However, an increase in theta wave activity may suggest that the task in the experiment was complex in nature and timely, showing an increase in cognitive processing, attention, internal exploration, and a decrease in arousal. Theta activity seems to be related to performance under time pressure. The increase in the theta wave activity appeared to be most prominent in the frontal region of the brain, therefore suggesting cognitive control. A decrease in theta wave activity has been suggested to be related to the recognition of fatigue or the sensation of fatigue, this is usually in the posterior cingulate cortex. It has not been determined if the theta wave activity in this area suggests activity of this area or if there is a relation.

Table 2.1: *The defining Differences between Physical and Mental Fatigue from a Neuro-electrical alternation viewpoint*

	Physical Fatigue	Mental Fatigue
Alpha	Decrease in alpha frequencies	Increase in alpha frequencies
Beta	Increase in beta frequencies	Decrease in beta frequencies
Theta	No significant role of theta frequencies	Increase in theta frequencies
Delta	No significant role of delta frequencies	No significant role of delta frequencies
Lobes Involved	Frontal, parietal, and temporal lobes	Frontal, parietal, temporal and occipital

2.6. The experience of Mental Fatigue as a sensation

There are neuropsychological studies that suggest that fatigue is more of a sensation (i.e. a subjective experience) than a physiological occurrence (i.e. objective and measurable event) when associated with physical activity (Gibson, et al., 2003) and it appears as if mental fatigue, at most, serves as a ‘biological alarm (Shigihara, et al., 2013). Some theories, such as the peripheral model of fatigue, suggest that afferent feedback is responsible for the sensation of fatigue due to changes in the peripheral organs during physical activity (Gibson, et al., 2003). These changes occur due to the depletion of resources in periphery of the body and not depletion of cognitive resources. However, non-sensory inputs, such as psychological and motivational factors, may also play an important role in this process to a greater or lesser extent (Gibson, et al., 2003), meaning that these factors may be enough to overcome the biological alarm which induces the sensation of fatigue.

There are also theories (Noakes, 2011) that suggest that there are multiple anatomical structures within the brain that are involved in the sensation of fatigue and the sensation of fatigue is probably not due to a singular peripheral, physiological factor. These theories are based on observations that hypnosis can alter the sensation of fatigue, expectations of demands influence the sensation of fatigue, and that individuals that suffer from Chronic Fatigue Syndrome report fatigue even during rest (Gibson, et al., 2003). This is further supported by studies that have found that a sensation of mental fatigue can be induced by sounds (Tanaka, et al., 2013). These observations seem to suggest that mental fatigue can exist in the absence of physical fatigue, which implies that it can be more of a perception than an actual state. This was notable on further investigations on the impact of mental fatigue on physical performance, where there appeared to be a decreased in physical performance but not physiological difference in fatigued participants compared to non-fatigued participants.

Suda, et al., (2009) investigated the correlation between brain functioning and subjective fatigue. The study made use of the visual- analogue scale (VAS) as a measure of subjective fatigue, as well as sleep duration and cerebral cortex reactivity during a verbal fluency task, measured by near-infrared spectroscopy (NIRS). The study found that there was a negative correlation between the VAS score and the amount of oxygenated haemoglobin concentration in the ventral lateral part of the frontal lobe compared to the dorsal part of the temporal lobe. Positive correlations were found between the amount of sleep the night before the study and the oxygen haemoglobin in the dorsal lateral prefrontal lobes. No significant correlations were found between the verbal fluency task and the amount of sleep the previous night. These results revealed that subjective feelings of mental fatigue are related to decreased reactions in the lateral frontal and superior temporal cortices and that these decreases in reactivates are unrelated to the amount of sleep. This suggests that mental fatigue experienced subjectively impacts the frontal and temporal regions of the brain and less influenced by the amount of rest.

Ishii, et al. (2013) went on to further investigate the sensation of fatigue, by examining whether the sensation of fatigue could be conditioned in individuals. The study made use of conditioning and control as part of the experiment. Metronome sounds were used as conditioning stimuli and two-back task trails were used to induce the sensation of fatigue; this was the unconditioned stimuli. MEG measurements were used to assess the reactive brain wavelengths whilst listening to the conditioning stimuli for a total of six minutes. The task trials were continued for a total of 60 minutes, followed by the conditioning stimuli for 30 minutes. The next day, MEG was used to assess neural activities for a total of six minutes whilst listening to the metronome sound and VAS was used to assess subjective fatigue. The control group followed the same procedure; however, the trial tasks were excluded. The results suggest that the sensation of fatigue, can indeed be induced by conditioning. The study found that there were significant changes in the insular cortex, which is positioned posteriorly of the frontal lobe and anteriorly of the temporal lobe, laterally. This supports information on the importance of the frontal and temporal lobes in the involvement of the sensation of fatigue.

There has been little research on the sensation of mental fatigue measured by an EEG. Psychological factors appear to be the basis behind the sensation of mental fatigue, which impacts the different brain regions differently, thus being unique in every individual.

2.7. Mental Fatigue, Physical Fatigue, and Sensation of Mental Fatigue

The previously mentioned literature all gives indications of how objective mental fatigue manifests in the brain through neural-electrical alternations and therefore changes in brain wave frequencies. However, many of these studies do not look at the link between physical fatigue induced by physical activity and mental fatigue. Is the supposed mental fatigue that is experienced after physical activity one that is only subjective in nature or can it be objectively measured by an EEG?

A study was conducted by Tanaka, et al., (2013) who investigated the neural effect of mental fatigue on physical fatigue by using a MEG. The study found that there was a correlation between alpha-band waves and mental fatigue, agreeing with previous studies such as those by Zhao, et al., (2012), Craig, et al., (2012) and

Barwick et al., (2013) mentioned on mental fatigue and the role of alpha wavelengths. The increase in alpha-band activity was predominately in the anterior cortex, this also shows alpha –anterization which was mentioned previously in the studies above. The authors interpreted the results, as indicating that mental fatigue results in the suppression of activities in the right anterior cingulate cortex during physical fatigue. The anterior cingulate cortex is involved with functioning of individuals performance by detecting errors and regulating behaviour (Carter, et al., 1998).

2.7. Conclusion

From the above, it is evident that the literature on the impact of physical fatigue on mental fatigue is not well researched. The aim of several studies above was to provide insight into the different constructs. The relationship between the two favours the impact of mental fatigue on physical performance. There is literature explaining the neurological patterns when one is experiencing mental and physical fatigue. Furthermore, the literature speaks of subjective and objective mental fatigue. This provides further insight into the mental functions and physical responses that are related to mental fatigue. Therefore, investigate the impact of physical activity on mental functions that may cause, mental fatigue and whether it will be objective or subjective in nature. The next chapter will look at the methodology used.

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter describes the methodology used in this study. The purpose of this chapter is to discuss the research design, research aims, hypothesis, participants and the instruments used in the study. Furthermore, discussion of statistical analysis is included.

3.2. Research Design

This study is based on a quasi-experimental design that included pre-intervention, a physical task and post-intervention.

Quasi-experimental design is a design that resembles characteristics of a real experiment; however, it lacks the control due to the type of intervention or task used (Wilson & MacLean, 2011). The physical task in the study involved the performance of physical activity, where participants were to complete the following timed exercise routine:

- 900m road run
- 500m machine row
- 15 calories on air-bike

The above exercise routine was designed by a sporting professional to ensure that the participants experienced symptoms of physical fatigue, after physical activity, which included shortness of breath, increased body temperature, increased heart rate and blood pressure (Rivera-Brown & Frontera, 2012). The sporting professional had completed a degree in Sports Sciences and had experience in strength and conditioning coaching within the South African context. The task mentioned above can be described as anaerobic exercise, where physical activity is short in durations and fuelled by energy sources within the muscle fibres and is independent on the use of inhaled oxygen as a source of energy (Patel, 2017). Therefore, ensuring the participants experienced measurable physical fatigue.

Within this quasi-experimental design, a pre-intervention/post-intervention was designed to be used in this study. This was used in order to evaluate the effects of change on overall performance due to the intervention. However, this overall design has some limitations that includes internal validity due to practice effects (Wilson & MacLean, 2011).

The outcome measures were as follows:

1) EEG recordings for a total of 240 seconds. The participants were instructed to keep their eyes closed for 120 seconds, followed by a period with their eyes open for 120 seconds. The set-up and administration were completed by the researcher after training.
2) Biological assessments of heart rate and blood pressure were recorded.
3) The RAVLT was administered to the participants by the researcher.
4) The participants were asked to complete the IFS.

This experimental design was chosen due to the nature of the research, where a task of physical activity, as mentioned above, was required to compare different states and experiences of participants, before and after the physical activity. Therefore, requiring purposive selection when selecting the participants.

Purposive sampling is a form of non-probability sampling technique in which individuals are selected due to a predetermined criterion and the selection is not random. (Wilson & MacLean, Sampling, 2011). The study made use of purposive sampling, as it required participants that are accustomed to physical activity. Purposive sampling was necessary for the nature of the study and due to the physical task, that was required, in order to exclude any cofounding variables, such as fitness levels and underlying issues that may result in fatigue. It is noted that this may be a disadvantage to the study as it limits the application of the results to a wider population that does not have the differentiating characteristics of the chosen sample group (Sharma, 2017).

A quantitative research design was chosen because the measurement instrument allowed for the collation and analysis of quantitative data. A quantitative research design is defined as research that requires employment of a hypothesis about the potential relationship between two variables, which enables a research questions to be developed (Wilson & MacLean, Qualitative Data Collection, 2011).

3.3. Participants

As previously mentioned, the study made use of purposive sampling, as it required participants that are accustomed to physical activity. Purposive sampling was necessary for the nature of the study and due to the physical task in which the participants had to complete during the study. The sample group was chosen in order to provide more information on the studies topic in the population of professional athletes.

Individuals with a history of at least twelve months of regular physical exercise (45 – 60 minutes of physical exercise 3 – 4 times a week) were asked to volunteer to participate in the study. The physical task in this study consisted of strenuous exercise, so it was preferred that the study made use of individuals that were accustomed to physical activity and excluded individuals that were not accustomed to physical activity, as unfit individuals and their experience of the physical task may introduce cofounding factors that would impact the validity of the results.

Participants were recruited, by notice boards, from sport clubs and gyms in Johannesburg and were between the ages of 20 and 30 years. The criteria mentioned above was placed on the notice board. The above age group was chosen to eliminate any variables that may have arisen due to age, such as levels of health. All of the participants had completed a secondary education. Individuals with a history of epilepsy or previous head injuries were excluded, due to the use of an EEG, which could skew results. Given the magnitude of data that is generated from an EEG study, only ten young adults were recruited for the study. Given the fact that male and female brain differs anatomically, gender was controlled by means of selecting five males and five females. Neurological conditions would affect EEG profiles, and in order to control for this artefact participants with a history of neurological disorders, such as epilepsy, were excluded from the study.

In conclusion, the inclusion criteria included:

- Healthy individuals that participate in regular physical exercise (45 – 60 minutes of physical exercise 3 – 4 times a week)
- Individuals in the vicinity of Johannesburg
- Individual between the ages of 20 – 30 years

The exclusion criteria included:

- History of neurological disorders
- Individuals that were not accustom to physical exercise
- Individuals under the age of 20 or older than 30 years of age

Table 3.1. *Mean age of participants*

Participant	Gender	Age
1	F	24
2	M	27
3	M	27
4	M	27
5	F	25
6	F	25
7	M	27
8	F	21
9	F	30
10	M	27
	MEAN	**26**
	STANDARD DEVIATION	**2.40**

3.4. Instruments

Assessments included one self-report questionnaire (IFS), that was administered during pre-intervention and post-intervention phase to measure the subjective aspect of mental fatigue. Two physical assessments (heart rate and blood pressure), one neuropsychological test (RALVT), and one neurophysiological recordings (EEG recordings), both of which were administered during pre-intervention and post-intervention phase to measure were used to measure the objective aspect of mental fatigue.

The Iowa Fatigue Scale (IFS) (Hartz, Bentler & Watson, 2003): The IFS was used to measure the participants' subjective state of mental fatigue. These 11 items (each item rated on a 5-point Likert scale) scale contains four subscales: cognitive, fatigue, energy, and productivity. 1-point was equivalent to "not at all" and 5-point was equivalent to "extremely". Total scores on this scale below 30 indicates the absence of fatigue, scores between 30 – 39 indicates fatigue and scores of 40 and above indicates severe fatigue. Correlations between the four subscales range from 0.49 to 0.66 (Hartz, et al. 2003) This is considered to have a low reliability and is a limitation to the study. However, it was chosen due to the length and design of the assessment, in order for participants to report their level of fatigue in a timely manner, to determine their subjective mental fatigue directly after the physical task.

Rey Auditory Verbal Learning Test (RAVLT) (Rey, 1964): This is a widely used neuropsychological test that evaluates a wide range of functions which are mainly (but not exclusively) related to short-term auditory memory as well as memory encoding and retrieval. The outcome measures of the RAVLT are immediate memory span, new learning, susceptibility to interference, and recognition memory. Due to the symptoms of cognitive mental fatigue, such as difficulty with memory and retention, the RAVLT was deemed an appropriate assessment to observe the differences in memory and retention, objective mental fatigue, before and after the physical task. Participants were read a list of 15 unrelated words, which were repeated over five trials and participants were asked to repeat the list after each trial. Participants were then read a list of 15 different words and were asked to repeat the first list of 15 words that were read to them. The reliability varies between 0.70 (for list A) and 0.38 (for list B). Snow, Tierney, Zorzitto, Fisher and Reid (1988) reported a test-retest reliability of 0.55 for a one-year interval between test and retest.

MacCartney-Filgnate and Vriezen (1988) correlated the test scores of the RAVLT with scores on similar instruments and reported correlations that varied between 0.50 and 0.65. The IFS is considered to have a low reliability and is a limitation to the study. This was chosen due to the level of education of the participants and timely manner that it could be administered, in order to record memory and retention immediately after the physical tasks.

BIOPAC® EEG recording equipment: This system was designed and developed to record brainwave activity across a number of cortical sites. The electrode cap was set-up and filled with conductive gel before it was placed on the participant's head, once complete, the electrode cap was cleaned and prepared for the next participant.

Given that the literature indicates that the frontal lobe, parietal lobes and temporal are involved in the sensation of mental fatigue, this study will be limited to readings from electrodes that correspond to the abovementioned lobes and readings from electrodes Fp1, Fp2, F2, F3 and F4 (See Figure 1) (Boksem, Meijman, & Lorist, 2005) (Schneider, et al, 2009) (Scheeringa, et al,.2008).

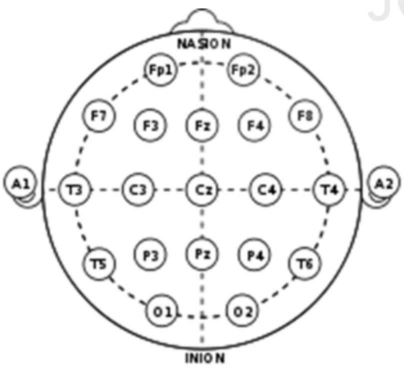

Figure 1: *Illustration of the International 10-20 electrode placement*

A benchmark recording of 120 seconds eyes closed and eyes open was complete during the pre-intervention and post-intervention phase of the study. The total 240 seconds allowed for enough time for epochs to be extracted from the data provided by the equipment. It was important for the participants to remain still throughout the EEG recordings, as movement can interfere with the accurate recordings of brainwave activity.

Polar Heart Rate Monitor: This monitor was used to determine the heart rate of the participants before and after the intervention as a means to determine physical exertion. The participants heart rate was measured as an average over time before the physical task and then measured again after the physical task, as an average over time.

Self-Measured Blood Pressure Monitoring: Blood pressure prior to, and following, the intervention in order to, along with heart rate, provide a measure of physical exertion. The usage of a cuff was included.

3.5. Procedure

Once approval from the University of Johannesburg Ethical Committee was given, the participants were invited to participate in the experiment and the procedure was explained to them before they agreed to participate in the study. Informed consent was given by all the participants (Appendix A). The study consisted of three stages, i.e. pre-intervention, physical task, and post-intervention.

A schedule was constructed, where participants could allocate a time that they were available for a full 30 minutes. Participants were assessed individually.

During the pre-intervention phase, participants took part, at a local gym in Johannesburg, in the following:

1) Participants were instructed to be seated on a chair, whilst the EEG equipment was placed on the participants by the researcher.

2) The participants were instructed to keep still throughout the duration of the EEG recordings.
3) EEG recordings were started by the research and ran for a total of 240 seconds.
    a. The participants were instructed to keep their eyes closed for 120 seconds, followed by a period with their eyes open for 120 seconds.
    b. EEG recordings were stopped at 240 seconds.
4) The EEG equipment was removed from the participants by the researcher.
5) The blood pressure machine and heart rate monitor were place on the participants' right arm and the cuff was placed correctly above the elbow, whilst the participant remained seated.

5) The participants' heart rate and blood pressure were recorded.
6) The blood pressure machine and heart rate monitor were removed from the participant's right arm.
7) The RAVLT was administered to the participants by the researcher.
    a. A list of words was read to the participants.
    b. The participant was asked to repeat the list of words for two sessions.
    c. A new list was read to the participants.
    d. The first list was asked to be repeated by the participants.
8) The participants were asked to complete the IFS.

During the physical task phase, the participants were asked to complete the follow time pressured physical activity as quickly as they could, without rest between each movement:

- 900m road run, marked by road signage
- 500m row on a rowing machine, placed in the gym. The rowing machine was set on a resistance of 10 for all participants.
- 15 calories on air-bike, placed in the gym. The air-bike was set on default settings and requires no load.

During the post-intervention phase, participants took part in the following:

1) Participants were instructed to be seated on a chair, whilst the EEG equipment was placed on the participants by the researcher.
2) The participants were instructed to keep still throughout the duration of the EEG recordings.
3) EEG recordings were started by the researcher and ran for a total of 240 seconds.
    a. The participants were instructed to keep their eyes closed for 120 seconds, followed by a period with their eyes open for 120 seconds.
    b. EEG recordings were stopped at 240 seconds.
4) The EEG equipment was removed from the participants by the researcher.

5) The blood pressure machine and heart rate monitor were place on the participants' right arm and the cuff was placed correctly above the elbow, whilst the participant remained seated.

9) The participants' heart rate and blood pressure were recorded.

10) The blood pressure machine and heart rate monitor were removed from the participants' right arm.

11) The RAVLT was administered to the participants by the researcher.

    a. A list of words was read to the participants. This list differed from the list in the pre-intervention phase of the study.

    b. The participant was asked to repeat the list of words for two sessions.

    c. A new list was read to the participants. This list differed from the list in the pre-intervention phase of the study.

    d. The first list was asked to be repeated by the participants.

12) The participants were asked to complete the IFS.

Participants were debriefed by the researcher following the post-test phase and given time to recover from the physical task.

3.6. Statistical Analysis

A spectral analysis combined with a Fast Fourier Transformation of the brainwaves was completed in order to transform the EEG graphs into absolute power scores (µV). The analysis as well as transformation was done by means of the AcqKnowledge ® software. These scores of predetermined epochs, across the different cortical sites were captured in a SPSS data file. Descriptive statistics were used to analyze measures such as heart rate, blood pressure and the IFS. Non-parametric data analysis consisted of determining within group differences between pre-intervention and post-intervention scores for all variables.

3.7. Ethics

Permission was granted by the Faculty of Humanities Ethics Committee at the University of Johannesburg, see appendix D. Participants were approached and informed consent was discussed and signed. See appendix A for the consent form that was used in the study. Confidentiality was consistent throughout the study, participants were allocated numbers rather than the usage of their names, as well as a safe and secure filing system was implemented. Participant numbers were assigned according to their intake and to keep their identity safe. Participants par-took in debriefing, where the nature of the study was explained to them in more depth. No referrals were required.

Participants were informed of the following:

1) Risks and discomforts: Participants were made aware of the discomforts associated with this research. Details included the intervention of physical activity and slight discomfort from the electrode cap whilst measuring brain wave frequencies.
2) Potential benefits: Participants were informed about the rationale of the study.
3) Protection of confidentiality: Participants were made aware that their personal information and test scores would be treated with confidentiality and would be securely protected. They were ensured that their personal information and test score would be used for statistical purposes only. Furthermore, participants

were informed that their identity would not be revealed in any publication resulting from this study.

4) Voluntary participation: Participants were informed that this research study was voluntary. They were informed that they may choose not to participate and may withdraw consent to participate at any time.

3.8. Conclusion

This chapter was intended to inform about the methodology and procedures used in the current study. The following chapter will discuss the results and findings from this study.

CHAPTER 4: RESULTS

4.1. Introduction

The purpose of this study was to investigate the relationship between physical activity and mental functions, further and to provide an understanding of the impact of physical activity on mental fatigue. The following three specific objectives were set to achieve the broad aim of the study:

1) To understand whether mental or cognitive functions, experienced due to physical activity, contribute to mental fatigue,
2) To compare the impact that physical activity has on mental fatigue.
3) To determine, if experienced, whether the mental fatigue from physical activity is an objective experience and measurable or whether the mental fatigue experienced is a sensation and only subjectively reported.

. It was hypothesized that mental fatigue, experienced after physical activity would be subjective in nature and experienced as a sensation, rather than physiological occurrence and would be self-reported. This was explored using data collected from the EEG readings, the IFS self-report questionnaire, physical assessments of heart rate and blood pressure and the RAVLT.

The sample size was not normally distributed due to a limited sample size and therefore non-parametric statistics were used. The results are reported firstly by the descriptive statistics and then followed by the results of the between-lobe differences, followed by the results of within-group differences in the frontal lobes, parietal lobes, and temporal lobes.

4.2. Descriptive Statistics

The study made use of the participation of ten participants, all of whom took part in all three phases of the study, the pre-intervention phase, the intervention phase, the post-intervention phase. There was a total of five female and five male participants. Below the descriptive statistics will be discussed.

The data collected by physical assessments of the heart rate and blood pressure was intended to evaluate the participant's exertion before and after the intervention. See Table 4.2.1 below.

Table 4.2.1. *Biological Markers Results*

Participant	HR		Blood Pressure Systolic		Blood Pressure Diastolic	
	Pre-Test HR	Post-Test HR	Pre-Test	Post-Test	Pre-Test	Post-Test
1	90	125	118	129	75	73
2	57	118	144	139	81	74
3	90	153	142	142	82	81
4	63	143	126	143	76	98
5	74	112	134	144	85	81
6	55	110	107	126	64	66
7	76	100	112	128	72	74
8	70	112	106	104	64	60
9	89	105	120	133	84	84
10	96	127	142	104	74	54
Mean	76	120,5	125,1	129,2	75,7	74,5
Variance	197,20	254,65	194,89	196,56	51,41	143,25
Standard Deviation	14,80	16,82	14,72	14,78	7,56	12,62

As expected, from the literature, the heart rate and blood pressure of the participants increased during the post-intervention phase of the study, indicating symptoms of physical fatigue due to the intervention.

The IFS data was collected and compared in Table 4.2.2. below during the pre-intervention and post-intervention phase of the study.

Table 4.2.2. *IFS scores of participants during the pre-intervention and post-intervention phase*

Participant	*Pre-test*	*Post-test*	*Differences*
1	29	32	-3
2	32	32	0
3	31	41	-10
4	24	38	-14
5	20	30	-10
6	24	21	3
7	29	27	2
8	28	23	5
9	21	25	-4
10	24	26	-2
MEAN	26,2	29,5	-3,3
VARIENCE	15,56	37,05	35,41
STANDARD DEVIATION	3,94	6,09	5,95

The results from the IFS indicate that six of the participants felt overall more subjective mentally fatigued after the intervention compared to before the intervention, three participants felt less subjectively fatigued after the intervention and one participant felt the same amount of mental fatigue, before and after the intervention.

The data collected from the RAVLT from the pre-intervention and post-intervention phase of the study is represented in Table 4.2.3 and 4.2.4 below.

Table 4.2.3. *The RAVLT scores of the participants during the pre-intervention phase of the study*

Participant	*Pre-intervention*				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1	5	10	10	5	6
2	9	12	12	8	11
3	9	14	13	5	14
4	8	11	12	6	9
5	9	12	12	6	12
6	11	14	15	9	11
7	13	14	12	12	13
8	9	13	13	3	12
9	10	12	13	6	13
10	8	8	9	2	9
MEAN	9,1	12	12,1	6,2	11
MEAN LOT Score	-12,3				
MEAN STPR	90,91				

Table 4.2.4. *The RAVLT scores of the participants during the post-intervention phase of the study*

Participant	*Post-intervention*				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1	7	10	14	6	11
2	11	10	13	9	9
3	12	13	15	10	15
4	7	9	11	4	8
5	5	14	13	7	10
6	12	15	14	9	15
7	13	15	15	10	15
8	10	14	15	13	13
9	6	7	8	6	5
10	8	8	9	5	8
MEAN	9,1	11,5	12,7	7,9	10,9
MEAN LOT Score	-12,2				
MEAN STPR	85.81				

The table shows an increase in RAVLT scores during the post-intervention phase when compared to the pre-intervention phase during trail four. The mean learning over trail score (LOT) is similar for pre-intervention and post-intervention phases of the study. The mean short-term percentage retention is less during the post-intervention phase of the study. The correlation calculated by Pearson Correlation between the two phases of the study is 0.9565.

The brain wave activity in the temporal, parietal and frontal lobes, is represented in Table 4.3. below, showing a difference in the means and standard deviations of each brain wave type.

Table 4.3. *Mean and Standard Deviation for each Lobe and Wave Frequency*

Lobe	Wave	Condition	Pre-Test		Post-Test	
			Mean	SD	Mean	SD
Temporal	Delta	Eyes Closed	0,02157	0,01005	0,01437	0,00989
		Eyes Open	0,0237	0,01052	0,01295	0,00848
	Theta	Eyes Closed	0,05508	0,01817	0,03969	0,01895
		Eyes Open	0,06289	0,0202	0,03619	0,01876
	Alpha	Eyes Closed	0,04903	0,01387	0,03483	0,0155
		Eyes Open	0,05502	0,01555	0,03219	0,01638
	Beta	Eyes Closed	0,01968	0,00386	0,01604	0,01266
		Eyes Open	0,02043	0,00627	0,01263	0,00702
Parietal	Delta	Eyes Closed	0,01476	0,00889	0,01544	0,01609
		Eyes Open	0,01604	0,01099	0,01225	0,00958
	Theta	Eyes Closed	0,04604	0,0141	0,0446	0,02648
		Eyes Open	0,05037	0,0212	0,03844	0,02056
	Alpha	Eyes Closed	0,04288	0,01446	0,0385	0,01792
		Eyes Open	0,04456	0,01585	0,03464	0,01742
	Beta	Eyes Closed	0,01513	0,00486	0,01395	0,00697
		Eyes Open	0,01616	0,00619	0,01193	0,00517

Frontal	Delta	Eyes Closed	0,02614	0,01201	0,01741	0,01159
		Eyes Open	0,02068	0,00822	0,016	0,01559
	Theta	Eyes Closed	0,02614	0,01201	0,04552	0,02006
		Eyes Open	0,02853	0,01332	0,04101	0,02958
	Alpha	Eyes Closed	0,07825	0,04524	0,0388	0,01551
		Eyes Open	0,06149	0,0159	0,03431	0,02257
	Beta	Eyes Closed	0,05152	0,02035	0,0148	0,0067
		Eyes Open	0,05046	0,00942	0,01294	0,00943

In the temporal lobe there was an overall decrease in delta, theta, alpha and beta brainwaves in the post-intervention phase when compared to the pre-intervention phase of the study.

In the parietal lobe, there was an increase in EC delta waves in the post-intervention phase when compared to the pre-intervention phase. However, an overall decrease in theta, alpha and beta brainwaves in the post-intervention phase when compared to the pre-intervention phase of the study.

In the frontal lobe there was an overall decrease in delta, theta, alpha and beta brainwaves in the post-intervention phase when compared to the pre-intervention phase of the study.

4.3. Non-parametric Statistics

4.3.1. Between-Lobe Differences

The Mann-Whitney U-test was used to compare the differences between groups – the differences between the conditions in each lobe as well as the wavelengths in each lobe. Significant differences were based upon 95 % accuracy and the two-tailed significance result was compared.

The results show that there was no significant difference found beta and alpha activity between each lobe in each condition. However, a Mann-Whitney test indicated that there was greater delta activity (mean rank = 13.20) during the pre-intervention eyes closed condition in the frontal lobe compared to parietal lobe (mean rank = 7.80), ($U = 23$, $Z = -2.041$, $p=0.043$). Furthermore, a Mann-Whitney test indicated that there was greater theta activity (mean rank = 13.20) during the pre-intervention eyes closed condition in the frontal lobe compared to parietal lobe (mean rank = 7.80), ($U = 23$, $Z = -2.041$, $p=0.043$).

4.3.2. Within-Group Differences

Wilcoxon Signed Rank Test was used to compare within-group hypotheses – conditions and brain wavelengths were compared. The data was run through SPSS which generated a Wilcoxon Signed Rank Test report. Significant differences were based upon 95 % accuracy and the two-tailed significance result was compared. The delta wave activity is first observed followed by theta wave activity, alpha wave activity then beta wave activity. The Wilcoxon Signed Rank Test results are in the following order: the temporal lobes, parietal lobes, and frontal lobes

4.3.2.1. Temporal Lobe

In the temporal lobe the following results found for delta wave activity: A Wilcoxon Signed-rank test indicated that the delta activity during pre-intervention eyes closed condition (mean rank = 5.78) is greater than in post-intervention eyes closed condition (mean rank = 3.00) ($Z = -2.497$, $p < 0.05$). A Wilcoxon Signed-rank test indicated that the delta activity during pre-intervention eyes closed condition (mean rank = 5.50) was greater than in post-intervention eyes open condition (mean rank =

0.00) ($Z = -2.803$, $p < 0.05$).A Wilcoxon Signed-rank test indicated that the delta activity during pre-intervention eyes open condition (mean rank = 5.78) was greater than in post-intervention eyes closed condition (mean rank = 3.00) ($Z = -2.599$, $p < 0.05$).A Wilcoxon Signed-rank test indicated that the delta activity during pre-intervention eyes open condition (mean rank = 5.78) was greater than in post-intervention eyes open condition (mean rank = 3.00) in the ($Z = -2.599$, $p < 0.05$). Therefore, this result shows an overall decrease in delta wave activity in the participants during post-invention conditions of the study in the temporal lobes.

In the temporal lobe the following results found for theta wave activity. A Wilcoxon Signed-rank test indicated that the theta activity during pre-intervention eyes closed condition (mean rank = 5.75) was greater than in post-intervention eyes closed condition (mean rank = 4.50) ($Z = -1.886$, $p < 0.05$). A Wilcoxon Signed-rank test indicated that the theta activity during post-intervention eyes open condition (mean rank = 7.00) was greater than in pre-intervention eyes closed condition (mean rank = 5.33) ($Z = -2.090$, $p < 0.05$).A Wilcoxon Signed-rank test indicated that the theta activity during pre-intervention eyes open condition (mean rank = 5.78) was greater than in post-intervention eyes closed condition (mean rank = 3.00) ($Z = -2.497$, $p < 0.05$).A Wilcoxon Signed-rank test indicated that the theta activity during pre-intervention eyes open condition (mean rank = 5.50) was greater than in post-intervention eyes open condition (mean rank = 0.00) ($Z = -2.803$, $p < 0.05$). Therefore, this results shows an overall decrease in theta wave activity in the participants during post-invention conditions of the study, changes in physiology due to the physical activity, in the temporal lobes.

In the temporal lobe the following results found for alpha wave activity. A Wilcoxon Signed-rank test indicated that the alpha activity during pre-intervention eyes closed condition (mean rank = 6.71) was greater than in post-intervention eyes closed condition (mean rank = 2.67) lobe ($Z = -1.988$, $p < 0.05$). A Wilcoxon Signed-rank test indicated that the alpha activity during pre-intervention eyes closed condition (mean rank = 6.13) was greater than in post-intervention eyes open condition (mean rank = 3.00) ($Z = -2.191$, $p < 0.05$).A Wilcoxon Signed-rank test indicated that the alpha activity during pre-intervention eyes open condition (mean rank = 5.78) was greater than in post-intervention eyes closed condition (mean rank = 3.00) ($Z = -2.497$, $p < 0.05$).A Wilcoxon Signed-rank test indicated that the alpha activity during pre-intervention eyes open condition (mean rank = 5.50) was greater than in post-intervention eyes open condition (mean rank = 0.00) ($Z = -2.803$, $p < 0.05$). Therefore, this results shows an overall decrease in alpha wave activity in the participants during post-invention conditions of the study in the temporal lobes.

In the temporal lobe the following results found for beta wave activity: A Wilcoxon Signed-rank test indicated that the beta activity during pre-intervention eyes closed condition (mean rank = 5.86) was greater than in post-intervention eyes open condition (mean rank = 4.67) ($Z = -2.497$, $p < 0.05$). A Wilcoxon Signed-rank test indicated that the alpha activity during pre-intervention eyes open condition (mean rank = 5.50) was greater than in post-intervention eyes open condition (mean rank = 0.00) ($Z = -2.803$, $p < 0.05$). Therefore, this results shows an overall decrease in beta wave activity in the participants during post-invention conditions of the study in the temporal lobes.

4.3.2.2. Parietal Lobe

In the parietal lobe the following results were found for delta wave activity: A Wilcoxon Signed-rank test indicates that the delta activity during pre-intervention eyes closed condition (mean rank = 7.00) was greater than in pre-intervention eyes open condition (mean rank = 2.00) ($Z = -2.191$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the delta activity during post-intervention eyes open condition (mean rank = 6.71) was greater than in pre-intervention eyes open condition (mean rank = 2.67) ($Z = -1.988$, $p < 0.05$). These results indicate an increase in delta wave activity during post-invention conditions of the study in the parietal lobe.

In the parietal lobe, the following results were found for theta and alpha wave activity: A Wilcoxon Signed-rank test indicates that the theta and alpha activity in the parietal lobe shows no significant difference between conditions.

In the parietal lobe the following results were found for beta wave activity: A Wilcoxon Signed-rank test indicates that the beta activity during post-intervention eyes open condition (mean rank = 6.86) was greater than in pre-intervention eyes closed condition (mean rank = 2.33) ($Z = -2.090$, $p < 0.05$). The results indicate an increase in beta wave activity during post-intervention conditions of the study in the parietal lobe.

4.3.2.3. Frontal Lobe

In the frontal lobe the following results were found for delta wave activity: A Wilcoxon Signed-rank test indicates that the delta activity during post-intervention eyes closed condition (mean rank = 6.25) was greater than in pre-intervention eyes closed condition (mean rank = 2.50) ($Z = -2.293$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the delta activity during post-intervention eyes open condition (mean rank = 6.86) was greater than in pre-intervention eyes closed condition (mean rank = 2.33) ($Z = -2.090$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the theta activity during post-intervention eyes closed condition (mean rank = 5.89) was greater than in pre-intervention eyes closed condition (mean rank = 2.00) ($Z = -2.599$, $p < 0.05$). The results indicate an increase in delta wave activity during post-intervention conditions of the study in the frontal lobe.

In the frontal lobe the following results were found for theta wave activity: A Wilcoxon Signed-rank test indicates that the theta activity during post-intervention eyes closed condition (mean rank = 7.00) was greater than in pre-intervention eyes open condition (mean rank = 5.33) ($Z = -2.090$, $p < 0.05$). The results indicate an increase in theta wave activity during post-intervention conditions of the study in the frontal lobe

In the frontal lobe the following results were found for alpha wave activity: A Wilcoxon Signed-rank test indicates that the alpha activity during post-intervention eyes closed condition (mean rank = 6.00) was greater than in pre-intervention eyes closed condition (mean rank = 1.00) ($Z = -2.701$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the alpha activity during post-intervention eyes open condition (mean rank = 5.50) was greater than in pre-intervention eyes closed condition (mean rank = 0.00) ($Z = -2.803$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the alpha activity during post-intervention eyes closed condition (mean rank = 5.50) was greater than in pre-intervention eyes open condition (mean rank = 0.00) ($Z = -2.803$, $p < 0.05$). The results indicate an increase in alpha wave activity during post-intervention conditions of the study in the frontal lobe

In the frontal lobe the following results were found for beta wave activity: A Wilcoxon Signed-rank test indicates that the beta activity during pre-intervention eyes open condition (mean rank = 5.50) was greater than in pre-intervention eyes closed condition (mean rank = 0.00) ($Z = -2.803$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the beta activity during post-intervention eyes closed condition (mean rank = 5.50) was greater than in pre-intervention eyes closed condition (mean rank = 0.00) ($Z = -2.803$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the beta activity during post-intervention eyes open condition (mean rank = 5.50) was greater than in pre-intervention eyes closed condition (mean rank = 0.00) ($Z = -2.803$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the beta activity during post-intervention eyes closed condition (mean rank = 5.89) was greater than in pre-intervention eyes open condition (mean rank = 2.00) ($Z = -2.599$, $p < 0.05$). A Wilcoxon Signed-rank test indicates that the beta activity during post-intervention eyes open condition (mean rank = 6.33) was greater than in pre-intervention eyes open condition (mean rank = 4.25) ($Z = -2.293$, $p < 0.05$). The results indicate an increase in beta wave activity during post-intervention conditions of the study in the frontal lobe

4.3.2.4. Summary of Within-Group Difference Results

Table 4.4. *Summary of Within-Group Differences Results*

Lobe	Post-Intervention Conditions
Temporal	Decrease in Delta, Theta, Alpha and Beta wave activity
Parietal	Increase in Delta and Beta wave activity
Frontal	Increase in Delta, Theta, Alpha and Beta wave activity

The results from the Within-Group Differences show that changes within the lobes during pre-intervention and post-intervention were significant.

4.4. Conclusion

From the above results the descriptive statistics indicate that participants had an increase in their heart rate and blood pressure after the invention of physical activity. The results also indicate that 60 percent of the participants reported feeling mentally fatigued after the invention and that there was an overall increase in trial four of the RAVLT administration, post-intervention. Furthermore, the descriptive statistics showed an overall decrease in the averages of delta, theta, alpha and beta brainwaves activity in the post-intervention phase in the temporal lobe. In the parietal lobe, there was an increase in EC delta waves in the post-intervention phase when compared to the pre-intervention phase. However, an overall decrease in theta, alpha and beta brainwaves in the post-intervention phase when compared to the pre-intervention phase of the study. In the frontal lobe there was an overall decrease in delta, theta, alpha and beta brainwaves in the post-intervention phase when compared to the pre-intervention phase of the study.

The results from the non-parametric statistics indicated that between-lobes there was no significant difference found beta and alpha activity between each lobe in each condition. However, there was greater delta activity during the pre-intervention eyes closed condition in the frontal lobe compared to parietal lobe. Furthermore, there was greater theta activity during the pre-intervention eyes closed condition in the frontal lobe compared to parietal lobe. Additionally, the results from within-group differences indicate an overall decrease of all the brainwave frequencies in the temporal lobe, during post-intervention conditions. In the parietal lobes, there was an increase in delta wave and beta wave activity in post-intervention eyes open conditions. Finally, in the frontal lobes there was an increase in all brain wave frequencies in post-intervention conditions.

Overall, the results indicate significant changes from pre-intervention and post-intervention phases of the study.

In the next chapter, the results will be discussed further.

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1. Introduction

This chapter intends to discuss the findings and results of this study in detail and how they may relate to previous research on the topic of mental fatigue. The research aims hypothesized that mental fatigue experienced after physical activity would be subjective in nature and not objectively measured on an EEG.

5.2. Biological Markers

Biological markers were measured pre-intervention and post-intervention to ensure that physical activity was sufficient. The results in Table 4.2 show that there was an overall increase in the participant's heart rates and blood pressure that indicates that physical fatigue was occurring due to the physical activity or intervention of the study. This correlates with the study by Kenney et al. (2015) that found common observable and measurable symptoms of physical fatigue after physical activity included increased heart rate and blood pressure.

5.3. Subjective Mental Fatigue

The Iowa Fatigue Scale (IFS) was used to measure participants' mental fatigue in the pre-intervention and post-phase of the study. The results in Table 4.2.2 indicated that 60 percent of the participants subjectively felt more fatigued during the post-intervention phase of the study. The 20 percent of participants that showed less fatigue in the post-intervention phase may have had higher fitness levels or non-sensory inputs and psychological constructs, as suggested by Gibson et al. (2003). This would require further investigation and is a recommendation for further research. These results are outliners from the normal data, that shows that there was an overall increase in subjective feelings of mental fatigue during the post-intervention phase of the study, whereas other participants reported an overall decrease in subjective feelings of mental fatigue. The literature on subjective mental fatigue after physical activity is limited and therefore, these results can be compared to reported subjective mental fatigue after cognitive tasks. Zhoa et al. (2012) found that participants' self-report of fatigue increased over time, correlating with the present study, which showed an increase of self-reported fatigue after a period of time and the intervention. Barwick et al. (2013) found that participants reported an increase in self-reported fatigue after neuropsychological assessments. These results suggest that the participants in this study followed a similar result of self-reported fatigue after cognitive tasks.

5.4. Memory and Recall

The RAVLT was adapted for the study to give insight into the participant's short - term memory and recall during the pre-intervention and post-intervention phase of the study. The results in Table 4.2.3 and 4.2.4demonstrate that recall, and memory appeared to remain fairly similar between the pre-intervention and post-intervention phase of the study. However, there was a significant difference between the results for the fourth trial of the RAVLT. During the fourth trial, the participants were introduced to a new list of word to recall. The reasons that the words were changed was to account for practice effects. All participants scored higher in Trial Four during the post-intervention phase of the study. This result may indicate that short-term memory and recall increased in the post-intervention phase, which does not correlate with previous literature. Johnson et al. (1998) argued that a symptom of mental fatigue is impaired short-term memory and recall. This may suggest that the participants in this study may not have experienced true mental fatigue, and therefore, the participants may have experienced subjective mental fatigue.

5.5. Results of Delta Wave Frequencies

The results from the study indicate numerous delta wave activity changes in the post-intervention phase of the study when compared to the pre-intervention phase of the study. According to Basar et al. (1999) and Stern et al. (2001) delta wave activity is most generally associated with sleep in individuals, and at times associated with decision making. For the purpose of this study, the association with decision making will be ruled out, as there were no cognitive tasks used to measure decision making during the post-intervention phase of the study. Delta wave activity is also most prominent during stage three of sleep.

It was found that there was an overall decrease in delta wave activity in temporal lobe during the post-intervention phase of the study. This overall decrease in delta wave activity indicates that the participants were not experiencing sleep or sleep-like states after participating in the post-intervention of physical activity. This decrease in delta waves correlates with the study done by Ishii, et al. (2014), in which the results indicated that subjective measure of mental fatigue correlated with a decrease in delta wave activities in the posterior cingulate cortex, which is located near the temporal lobes.

In the parietal lobes it was found that there was greater delta wave activity in the pre-intervention phase when the participants' eyes were closed compared to when they were open. This result could be due to the action of having the participants' eyes closed, as this may induce sleep-like waves. There was also an increase in delta wave activity during the post-intervention phase when the participants' eyes were open compared to the pre-intervention phase when the participants' eyes were open. These results do not correlate with any previous literature mentioned in the study. This increase may be recording a type of decrease in arousal of the individual or cofounding effects such as having to close their eyes.

In the frontal lobe it was found that there was greater delta wave activity in the post-intervention phase of the study when the participants' eyes were open and closed when compared to the pre-intervention phase of the study when participants' eyes were closed. This may indicate a decrease in arousal. The frontal lobes showed greater delta wave activity during the pre-intervention phase when the participants' eyes were closed compared to the parietal lobe.

It is suggested that delta waves are not prominent in the study of objective mental fatigue. The decrease of the delta waves found in the temporal lobes of this study correlates with the study by Ishii, et al. (2014), which suggest that a decrease in delta waves within the temporal region is correlated to subjective mental fatigue. The result of increasing delta waves within the parietal and frontal lobes may suggest a slight decrease in arousal of the participants and may have been impacted by the action of the participants closing their eyes.

5.6. Results of Theta Wave Frequencies

The results from the study indicate numerous theta wave activity changes in the post-intervention phase of the study when compared to the pre-intervention phase of the study. Theta waves are generally associated with low levels of alertness, cognitive processing, and attention (Stern et al., 2001). Studies done by Basar et al. (1999) have demonstrated that theta wave activity was observed as a response during actions that require internal exploration, internal searching, and motor behaviour; in addition to being associated with cortico-hippocampal interaction.

In the temporal lobe, the results showed an overall decrease in theta wave activity during the post-intervention phase of the study compared to the pre-intervention phase of the study. This result correlates with the study done by Ishii et al. (2014), where they found a decrease in theta wave frequencies in the posterior cingulate cortex, situated near the temporal region, to be associated with subjective feelings of mental fatigue.

In the parietal lobe, results showed no change in theta activity when comparing pre-intervention and post-intervention phase of the study. This result does not correlate with the study done by Craig et al. (2012), where they found an overall increase in theta wave frequencies in the parietal lobe. However, this is only one study and would require more investigation.

In the frontal lobe, results show greater theta wave activity in the post-intervention phase eyes-closed condition compared to the post-intervention eyes-open conditions. There was an increased theta activity in post-intervention phase eyes closed compared to pre-intervention eyes open condition. This increase in theta wave activity correlates well with studies done by Boskem et al. (2005), Scheering et al. (2008), Craig et al. (2012) and Barwick et al. (2013) where an increase in theta wave activity in the frontal lobes suggests mental fatigue. Another possible reason why the theta wave activity was higher during eyes-closed condition may be because of the action of having your eyes closed may induce a sensation of decreased arousal, which is a common cause of increased theta wave activity. There was great theta activity in the frontal lobe pre-intervention eyes closed condition compared to the parietal lobe of the same condition.

5.7. Results of Alpha Wave Frequencies

The results from the study indicate numerous alpha wave activity changes in the post-intervention phase of the study when compared to the pre-intervention phase of the study. Alpha waves are associated with awake and relaxed states in individuals (Stern et al.2001). Reduction in alpha waves are associated with the performance of a physical task (Raveendran, 2007).

In the temporal lobes, the results showed that there was an overall decrease in the alpha wave activity during the post-intervention phase of the study compared to the pre-intervention phase of the study. This result does not correlate with any of the previously mentioned literature. The decrease in the alpha wave frequencies in the temporal lobe may suggest a slight decrease in arousal and that the participants were no longer awake or relaxed.

In the parietal lobes, the results showed that there was no significant change in the alpha waves during the pre-intervention and post-intervention phase of the study. This result does not correlate with any previous literature, that found that alpha wave activity to be important in measuring mental fatigue.

In the frontal lobes, the results show that there was an increase in alpha wave activity during the post-intervention phase when compared to the pre-intervention phase of the study. This result correlates with previous literature where mental fatigue was associated with an increase in alpha wave frequencies in the studies by

Craig et al. (2012), Zhao et al. (2012) and Barwick et al. (2013). All of the above-mentioned studies found an increase in alpha wave activity in the frontal lobe to be associated with self-reported (subjective) mental fatigue. The increase in alpha wave activity in the frontal lobe region may further suggest anterior movement of alpha wave activity, a distinct characteristic of mental fatigue.

The result of the alpha wave frequencies in this study suggest that mental fatigue was present after the intervention, mainly in the frontal lobe region.

5.8. Results of Beta Wave Frequencies

The results from the study indicate numerous beta wave activity changes in the post-intervention phase of the study when compared to the pre-intervention phase of the study. Beta wave activity is associated with alert individuals and performance of cognitive activities (Stern et al.2001).

In the temporal lobes, the results indicated that there was a decrease in beta wave activity during the post-intervention eyes open phase compared to the pre-intervention eyes open and closed phase. This decrease in beta wave frequencies suggest a decrease in arousal of the participants, post-intervention. This result correlates with studies by Zhao et al. (2012).

In the parietal lobe, the results indicated that there was greater beta wave activity during the post-intervention eyes open phase compared to the pre-intervention eyes closed phase. This result does not correlate with any previous literature and may suggest alertness in the participants, due to the role of beta wave activity in altered individuals.

In the frontal lobe, the results indicated that there was greater beta wave activity in the post-intervention phase when compared to the pre-intervention phase of the study. This result correlates with studies by Craig et al. (2012) and Boskem et al. (2005). These studies found the increase in beta wave frequencies in the frontal lobe to be associated with mental fatigue. However, there was greater beta wave activity in the pre-intervention eyes open phase compared to the pre-intervention eyes closed phase. The action of having eyes closed may induce frequencies associated with sleep and therefore, there would be less beta wave frequencies when eyes are closed.

The results from this study, in terms of beta wave activity show strong correlations with previous studies in terms of beta wave activity increase in the frontal lobes. The decrease in beta waves suggest decrease in arousal of the participant post-intervention.

5.9. Summary of Results

From the above, there appears to be limited evidence to indicate that there were signs of objective mental fatigue in the participants. According to the results, the participants may have experienced a sensation of mental fatigue and that the mental fatigue they experienced appeared to be subjective in nature.

5.10. Limitations to study

The limitations of the study do need to be considered, including the sample size and validity and reliability of instruments and their use in a South African context. The concept of mental fatigue is a complex one that may involve many varying factors, such as perceived effort, motivation and concepts such as memory of past experiences, therefore determining a definite answer to an individual's experience of mental fatigue is a challenging task and requires further investigation overall. Further limitations could include that the fitness levels of the participants were not controlled.

5.11. Implications of the Study and Recommendations for Future Research

The results of this study can provide valuable information for future research on the topic of mental fatigue. In addition, it may provide support for the field of sports psychology and the training of professional athletes and military service personal. This may assistance in enhancing their physical and mental preparation for a game or mission ahead. This could include psychoeducational programmes around mental fatigue and personalized therapy plans in order to work on the experience of mental fatigue. Furthermore, the symptoms of mental fatigue such an increased distractibility and decreased flexibility (Boksem et al. 2005) and aversion to continue tasks (Desmond & Hancock, 2001) make it an important state to study, in order to provide insight into individuals or patients that may be experiencing similar symptoms and how individuals may recover from mental fatigue.

The following is a list of recommendations for a future study would of mental fatigue, making use of a similar methodology:

1) To make use of larger sample size of professional athletes
2) To have a control over the fitness level of the participants
3) To make use of more reliable and valid instruments that apply to the South African context
4) To make use of more accurate objective instruments, such as a fMRI
5) To conduct a longitudinal study to see the results over a longer period of time, in order to measure the consistency of the results.

From the research the following broader questions emanated, and should be considered for future research:

1) The differences between subjective mental fatigue experienced in different level of professional athletes
2) The overall impact that physical activity has on subjective mental fatigue
3) The factor that contribute to the feelings of subjective mental fatigue

Overall, from this study, it is suggested that after physical activity, any mental fatigue that is experienced or reported may be subjective in nature, and similar to a sensation rather than measurable or objective mental fatigue. Therefore, the null hypothesis may be rejected, and the alternative hypothesis may be accepted. However, due to the listed limitations to this study, further research would be required to determine a final conclusion.

REFERENCES

Barwick, F., Arnett, P., & Slobounov, S. (2011). EEG correlates of fatigue during administration of a neuropsychological test battery. *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology*, *123*(2), 278 - 284.

Barwick, F., Arnett, P., & Slobounov, S. (2012). EEG correlates of fatigue during administration of a neuropsychological test battery. *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology*, *123*(2), 278–284. doi: 10.1016/j.clinph.2011.06.027

Basar, E., Basor-Eroglu, C., Karakas, S., & Schurmann, M. (1999). Are cognitive processes manifested in event-related gamma, alpha, theta, and delta oscillations in the EEG? *Neuroscience Letters, 259*, 165 - 168. doi: 0304-3940/99

Boksem, M. S., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: an ERP study. *Cognitive Brain Research*, 107-116.

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior Cingulate Cortex, Error Detection, and the Online Monitoring of Performance. *Science*, 747-749.

Cheng, S., & Hsu, H. (2011). Mental Fatigue Measurement Using EEG. Risk Management Trends, Giancarlo Nota, *IntechOpen*. doi: 10.5772/16376

Connon, H. (2016). *The effect of mental fatigue on the psychobiological response to a 10km cycling time trial: a neuroergonomic approach.*

Craig, A., Tran, Y., Wijesuriya, N., & Nguyen , H. (2012). Regional brain wave activity changes associated with fatigue. *Psychophysiology, 49*(4), 574-582. doi:https://doi.org/10.1111/j.1469-8986.2011.01329.x

Desmond, P. A., & Hancock, P. A. (2001). Active and passive fatigue states. In P. H. In: Desmond, *Stress, Workload and Fatigue* (pp. 455–465). New Jersey: Lawrence Erlbaum Associates.

Desmond, P. A., & Matthews, G. (1997). Implications of task-induced fatigue effects for in-vehicle countermeasures to driver fatigue. *Accident Analysis and Prevention*.

Eston, R., Faulkner, J., Gibson, A. S., Noakes, T., & Parfitt, G. (2007). The effects of antecedent faiguing activity on the relationship between perceived and physiological activity during a constant load exercise task. *Psychophysiology*, 779-786.

Gibson, A. S., Baden, D. A., Lambert, M. I., Lambert, E. V., Harley, Y. X., Hampson, D., . . . Noakes, T. D. (2003). The Conscious Perception of the Sensation of Fatigue. *Sports Med*, 163-176.

Hanslmayr, S., Gross, J., Klimeschenen, W., Shapiro. K.L. (2011). The role of alpha oscillations in temporal attention. *Brain Research Reviews, 67*(1-2), 331 -343.

Hartz. A., Bentler. S., Watson. D. (2003). Measuring fatigue severity in primary care patients, *Journal of Psychosomatic Research, 54*(6), 515-521.

Ishii, A., Tanaka, M., Yamano, E., & Watanabe, Y. (2014). The neural substrates of physical fatigue sensation to evaluate ourselves: a magnetoencephalography study. *Neuroscience*, 60 - 67.

Johansson, B., Bjuhr, H., & Ronnback, L. (2012). Mindfulness-based stress reduction (MBSR) improves long-term mental fatigue after stroke or traumatic brain injury. *Brain Injury*, 1621 - 1628. doi:https://doi.org/10.3109/02699052.2012.700082

Johnson, S., DeLuca, J., & Diamond, B. (1998). Memory dysfunctioning in fatiguing illness: Examing interference and distraction in short-term memory. *Cognitive Neuroscience, 3*, 269-285.

Kato, Y., Endo, H., & Kizuka, T. (2009). Mental fatigue and impaired response processes: event-related brain potentials in a Go/NoGo task. *International Journal of Psychophysiology*, 204 - 211.

Kenney, L. W., Wilmore, J., & Costill , D. (2015). Energy Expenditure and Fatigue. In L. W. Kenney, J. Wilmore, & D. Costill, *Physiology of Sport and Exercise 6th Edition* (pp. 120 - 147). Human Kinetics.

Klimeschen, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Science, 16*(12), 606–617. doi: 10.1016/j.tics.2012.10.007

Klimeschen, W., Schack, B., & Sauseng, P. (2005). The Functional Significance of Theta and Upper Alpha Oscillations. *Experimental Psychology, 52*(2), 99-108. doi:10.1027/1618-3169.52.2.99

Kubitz K., Mott A. (1996). EEG power spectral densities during and after cycle ergometer exercise. *Research Quarterly for Exercise and Sport, 67*(1), 91-96.

MacMahon, C., & Schücker, L. (2014). Cognitive fatigue effects on physical performance during running. *Journal of Sport & Exercise Psychology*, 375-381.

Mah, C. D., Mah , K. E., Kezirian, E. J., & Dement, W. C. (2011). The Effects of Sleep Extension on the Athletic Performance of Collegiate Basketball Players. *Sleep, 34*(7), 943-950. doi: 10.5665/SLEEP.1132

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology, 3*(106), 857-864.

Macartney-Filgate, M. S., Vrieze, E. R. (1988). Intercorrelation of clinical tests of verbal memory. *Arch Clin Neuropsychol. 3*(2): 121-126.

Millett, D. (2001). Hans Berger: From Psychic Energy to the EEG. *Perspectives in Biology and Medicine, 44*(4), 522-542. doi:10.1353/pbm.2001.0070

Moraes, Helena, Ferreira, Camila, Deslandes, Andréa, Cagy, Mauricio, Pompeu, Fernando, Ribeiro, Pedro, & Piedade, Roberto. (2007). Alterações eletrencefalográficas nas bandas de frequência alfa e beta após exercício de esforço máximo. *Arquivos de Neuro-Psiquiatria*, *65*(3a), 637-641. https://dx.doi.org/10.1590/S0004-282X2007000400018

Noakes, T. D. (2011). Time to move beyond a brainless exercise physiology: The evidence for complex regulation of human exercise performance. *Journal of Applied Physiology, nutrition, and metabolism, 36*(1), 23-35.

Offner, M. (1911). Measurements of Mental Fatigue. In M. Offner, *Mental Fatigue*. Baltimore: Warwick & York.

Patel, H., Alkhawam, H., Madanieh, R., Shah, N., Kosmas, C. E., & Vittorio, T. J. (2017). Aerobic *vs* anaerobic exercise training effects on the cardiovascular system. *World journal of cardiology*, *9*(2), 134–138. doi: 10.4330/wjc.v9.i2.134

Priyanka, A., Abhang Bharti, W., & Gawali Suresh , C. (2016). Technical Aspects of Brain Rhythms and Speech Parameters. In *Introduction to EEG- and Speech-Based Emotion Recognition*, 51-79. doi:doi.org/10.1016/B978-0-12-804490-2.00003-8

Punja, S., Shamseer, L., Olson, K., & Vohra, S. (2014). Rhodiola rosea for mental and physical fatigue in nursing students: a randomized controlled trial. *PloS one*, *9*(9), e108416. doi: doi.org/10.1371/journal.pone.0108416

Raveendran P. (2007) Comparison of different Montages on to EEG classification. *International Conference on Biomedical Engineering 2006*. (IFMBE Proceedings, Vol 15, pp 365-368). Berlin, Heidelberg: Springer.

Reber, A. S., Allen, R., & Reber, E. S. (2009). *Penguin Dictionary of Psychology.* New York: Penguin Books.

Rey, A. (1964). The Clincal Psychological Examination. Paris: Presses Universitaires de France.

Rivera-Brown, A. M., & Frontera, W. R. (2012). Principles of Exercise Physiology: Responses to Acute Exercise and Long-term Adaptations to Training. *PM & R : the journal of injury, function, and rehabilitation, 4(11), 797–804. doi: 10.1016/j.pmrj.2012.10.007*

Scheeringa, R., Petersson, R., Oostenveld, D.G., Norris, P., Hagoort, M. C. (2008). Trial-by-trial coupling between EEG and BOLD identifies networks related to alpha and theta EEG power increases during working memory maintenance. *NeuroImage, 44*(3), 1224 - 1238.

Schiphof-Godart, L., Roelands, B., & Hettinga, F. (2018). Drive in Sports: How Mental Fatigue Affects Endurance Performance. *Frontiers in Psychology, 9*, 1383. doi:10.3389/fpsyg.2018.01383

Schneider. S., Brümmer. V., Abel. A., Askew. C. D., Strüder. H. K. (2009). Changes in brain cortical activity measured by EEG are related to individual exercise preferences. *Physiology & Behavior, 98*(4), 47-452.

Sharma, G. (2017). Pros and cons of different sampling techniques. *International Journal of Applied Research*, 749-752.

Shigihara, Y., Tanaka, M., Ishii, A., Kanai, E., Funakura, M., & Watanabe, Y. (2013). Two types of mental fatigue affect spontaneous oscillatory brain activities in different ways. *Behaviour and Brain Function*, 1-13.

Smith, M. R., Coutts, A. J., Merlini, M., Deprez, M., Lenoir, M., & Marcora, S. M. (2016). Mental fatigue impairs soccer-specific physical and technical performance. *Medicine & Science in Sports & Exercise, 48*(2), 267 - 276. doi: 10.1249/MSS.0000000000000762.

Snow, W. G., Tierney, M. C., Zorzitto, M. L., Fisher, R. H., & Reid, D.W. (1988). One-year test–retest reliability of selected tests in older adults. *Journal of Clinical and Experimental Neuropsychology, 11*(4), 423-428. doi: 10.1080/01688638908400903

Stern, R. M., Ray, W. J., & Quigley, K. S. (2001). Brain Electroencephalography. *Psychophysiological Recordings* (pp. 80- 81). New York: Oxford University Press.

Suda, M., Fukuda, M., Sato, T., Iwata, S., Song, M., Kameyama, M., & Mikuni, M. (2009). Subjective feeling of psychological fatigue is related to decreased reactivity in ventrolateral prefrontal cortex. *Brain Research*, *1252*, 152–160. https://doi.org/10.1016/j.brainres.2008.11.077

Tanaka, M., & Watanabe, Y. (2011). Neural compensation mechanisms to regulate motor output during physical fatigue. *Brain Research*, *1395,* 46 - 52. doi: 10.1016/j.brainres.2011.04.041

Tanaka, M., Ishii, A., Iwamae, M., Kim, C., Yamano, E., & Wantabe, Y. (2013). Fatigue sensation induced by the sounds associated with mental fatigue and its related neural activities: revealed by magnetoencephalography. *Behavioral and Brain Functions, 9*(24). doi:https://doi.org/10.1186/1744-9081-9-24

Teplan, M. (2002). Fundamentals of EEG measurement. *Measurement of Science Review*, *2*, 1-11.

Thalía, H. (2013). The functional significance of delta oscillations in cognitive processing. *Frontiers in Integrative Neuroscience, 7*(83). doi: 10.3389/fnint.2013.00083

Van der Linden, D., & Eling, P. (2006). Mental fatigue disturbs local processing more than global processing. *Psychological Research-Psychologische Forschung 70*, 395–402.

Völker, I., Kirchner, C., & Bock, L. O. (2016). On the relationship between subjective and objective measures of fatigue. *Ergonomics, 59*(9), 1259 - 1263. doi:10.1080/00140139.2015.1110622

Wascher, E., Rasch, B., Sänger, J., Hoffmann, S., Schneider, D., Rinkenauer, G., . . . Gutberlet, I. (2014). Frontal theta activity reflects distinct aspects of mental fatigue. *Biological psychology*, 57-65.

Wilson, S., & MacLean, R. (2011a). Qualitative Data Collection. In S. Wilson, & R. MacLean, *Research Methods and Data* (pp. 198 - 201). Berkshire: McGraw-Hill.

Wilson, S., & MacLean, R. (2011b). Quasi-Experimental and Development Design. In S. Wilson, & R. MacLean, *Research Methods and Data Anaylsis for Psychology* (pp. 144 - 149). Berkshire: McGraw-Hill.

Zhao C., Zhao M., Liu J., Zheng C. (2012). Electroencephalogram and electrocardiograph assessment of mental fatigue in a driving simulator. *Accid. Anal. Prev. 45*, 83–90. doi: 10.1016/j.aap.2011.11.019

APPENDIX

Appendix A: Consent of Participation

Consent Form for Participation in a Research Study
University of Johannesburg

Dear Participant

You are invited to participate in a MA research study conducted by Meghann Bruce. The purpose of this research is to examine the relationship between fatigue and physical activity.

Your participation will involve measurement of your blood pressure, heart rate, body temperature and brain wave frequencies. You will be asked to fill in a questionnaire and complete a learning test. This study includes an intervention of physical activity.

Risks and discomforts

There are certain discomforts associated with this research. They include the intervention of physical activity and slight discomfort from the electrode cap whilst measuring brain wave frequencies.

Potential benefits

There are no known benefits to you that would result from your participation in this research other than a greater insight into fatigue and adding to research on fatigue.

Protection of confidentiality

Your personal information and test scores will be treated with confidentiality and will be securely protected. Your personal information and test score will be used for statistical purposes. Your identity will not be revealed in any publication resulting from this study.

Voluntary participation

Your participation in this research study is voluntary. You may choose not to participate, and you may withdraw your consent to participate at any time. You will not be penalized in any way should you decide not to participate or to withdraw from this study.

Contact information

If you have any questions or concerns about this study or if any problems arise, please contact Meghann Bruce at 073 270 5407.

Consent

I have read this consent form and have been given the opportunity to ask questions. I give my consent to participate in this study.

Participant's signature________________________________ Date: _________________

A copy of this consent form should be given to you.

Appendix B: Participation Letter

FACULTY OF HUMANITIES

MASTERS RESEARCH PARTICIPATION LETTER FOR RESEARCH CONDUCTED BY

MEGHANN BRUCE

Dear Possible Participants

Thank you for taking the time to consider being a participant in my current research on fatigue and physical activity. I am looking for 5 female and 5 male participants. Below is more information on the research and participation in the research.

In order to participate:

- You must be between the ages of 20 – 30 years
- Be at an acceptable fitness level (Currently involved in 3- 4 sessions of physical activity/exercise a week)
- Have no heart conditions
- Have no history of seizure or epilepsy
- Not be pregnant
- Not be on any stimulants (Ritalin, Concerta etc)

What you need to know:

- Participation is completely voluntary, and you may withdraw from participation at any stage.
- Your personal information and results will be confidential and used for statistical purposes only.
- Your name will not be mentioned in the study.
- You will be debriefed after participation and your results can be shared with you if you would like.
- The length of your participation will not be longer than 1 hour.

The research will involve:

- The use of an electroencephalogram (EEG), this device is used to record wavelengths of brain activity in various part of your brain. Please note that an electrode cap will have to be worn and I foresee no possible harm or un-discomfort when you are wearing the electrode cap.
- Hand-written and verbal tests to measure different factors that relate to fatigue.
- A session on physical activity that will physically fatigue you.
- Recording of biological factors such as body temperature, heart rate and blood pressure.

If you have questions about participation, please do not hesitate to contact me. If you would like to participate, please fill in the form attached, and I will be in contact with you. Thank you for your time.

Kind Regards Meghann Bruce - 073 270 5407

Appendix C: Participant Information Form

Participant Number:____________________________________
Date:____
Time:____

Information Sheet

Participant Information

Full Name: ____

Cellphone: __________________________ Alternate Phone: ______________________________

Email ____

Birth Date: ________________ Current Age: _______________________________

Male/Female: ____

Other Information

Please circle YES/NO and specify if ask to.

Have you consumed caffeine today? YES/NO If YES, how many hours ago? ________________ ______________

Have you ever had a brain injury/seizures/epilepsy? YES/NO

Have you done anything today that differs from your daily routine? YES/NO - If YES, please specify below

____

Appendix D: Ethical Clearance

UNIVERSITY OF JOHANNESBURG

FACULTY OF HUMANTIES

RESEARCH ETHICS COMMITTEE

21 September 2015

REC 01-10-2015

STUDENT : M Bruce

STUDENT NUMBER : 200908085

TITLE OF RESEARCH PROJECT: The Subjective and Objective Effect of Physical Activity on Mental Fatigue

DEPARTMENT : Psychology

DEGREE OR PROGRAMME : MA Psychology

SUPERVISOR/S : Prof A Burke

Dear Ms Bruce

The Faculty Research Ethics Committee has scrutinised your research proposal and confirm that it complies with the approved ethical standards of the Faculty of Humanities; University of Johannesburg.

The REC would like to extend their best wishes to you with your postgraduate studies.

Yours sincerely,

Prof Tharina Guse
Chair: Faculty of Humanities REC
Tel: 011 559 3248